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Article

ArcGIS based Analysis of Multiple Accident Areas Caused by Marine Plastic Litter in Republic of Korea

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Abstract

Marine accidents involving the entanglement of marine litter have continued to increase, with over 300 to 400 cases per year according to the statistical agency. Entanglement of marine litter may also lead to large-scale marine accidents which cause capsizing and sinking, thereby further causing detrimental casualties and material damages, and thus exceptional attention and care are required. In this study, Incheon, Busan, and Geoje and Tongyeong were found to be the high-frequency locations for accidents, which were selected by considering the ArcGIS analysis about the marine accidents of entanglement of marine litter and the occurrence frequency by the standard. The characteristics of the multiple accident areas involving entanglement of marine litter were the coastal cities where fishing facilities or marine leisure related conditions were activated, with the port which handles much of the traffic of outbound and inbound vessels located nearby. Marine plastic pollution impacts not only the marine ecosystem and food chain, but also the hull and engine of ships, and may further pose threats to the safety of vessels and crews. It is necessary to find a common link between the relevant areas and to strive to remove the root causes of marine accidents by reducing marine litter.

***Keywords**: Marine litter, ArcGIS analysis, Multiple accident areas, Marine plastic pollution, Common link*

1. Introduction

Global plastic production began to increase in 1950s and is producing up to 359 million tons in 2018[1]. In general, many of the items used on a daily basis, such as containers, vinyl, and strings, as well as disposable items known as plastic, are made of plastic, and the world without plastic has become an unimaginable reality for modern people[2-3]. This increase in plastic production leads to an increase in the inflow of waste plastic into the ocean[4]. In fact, waste plastics aggregated on the coast of Korea in 2021 accounted for the largest portion at 46%[5].

But surprisingly, research on the impacts of marine plastic has already begun since 1972[6], and social interest has increased significantly as marine plastic has been released to the world. The impact of marine plastics can act as a catalyst for large-scale marine accidents as well as marine ecosystems[7] and humans, which is even more serious[8-9]. For example, the "Capsizing accident of West Sea Ferry, passenger ship," which occurred on Sunday, October 10, 1993, was a major accident that caused serious damage when discarded plastic (rope) wrapped around the hull. At that time, the West Sea Ferry did not properly control the boarding of passengers, exceeding 141 people (221 people), and cargo such as salted shrimp also departed in excess of 6.5 tons. Furthermore, many of the passengers on board stayed on the ship's starboard to avoid the sea breeze, so the hull sailed with the ship leaning to the right. At that moment, the ship lost its resilience and eventually sank when a nylon rope floating in the sea wrapped around the propulsion axis of both side. The accident caused 292 people on board to drown or die on board[10].

In addition, "Capsizing accident of dolphin, fishing vessel," occurred due to damage to the propulsion shaft and shoe piece in 2015. Dolphin crew members, including anglers, boarded dispersedly in the steering room and crew room, but did not wear it because they were wet despite carrying personal life vests or having life vests on board. In such a situation, shoe piece, which was wound with an unknown rope of cause, was damaged or dislodged by tension caused by the rotation of the propeller, which led to a sharp drop in speed, a slope of the hull, and a decrease in control performance. Eventually, the ship lost its resilience due to the flared waves and overturned with the main engine (ME) turned off. In addition, 18 of the 21 crew members, including the captain, were killed and missing[11].

The international community has been aware of the seriousness of marine plastic management[12-13]. In that respect, the Republic of Korea enacted a bill to recover marine waste by dividing it into coast, floating, and sedimentation. However, the statute mainly focuses on preventing, improving, responding, and restoring marine pollution, and

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managing and reducing marine pollutant generation. In other words, the current domestic law does not reflect ship operation-oriented contents such as how to respond to marine accidents caused by marine waste, how to cope with ship-owners, captains, and crews, facilities, and related systems are also somewhat insufficient. In fact, marine plastic waste such as fishing nets and ropes continue to affect ship operations, and marine accidents caused by marine litter account for an average of 11% (more than 300 cases per year) of all marine accidents[14]. These figures are increasing year by year. Therefore, We need to recognize the importance of preventing human, environmental[15], economic, and social damage[16] due to marine accidents caused by marine plastics in advance, and to investigate and analyze the multiple accident areas caused by marine plastic and the conditions.

In this study, the accident statistics were surveyed by focusing on floating marine litter, particularly plastic while limiting the examination to entanglement accidents involving floating marine litter. Specifically, it is intended to perform a statistical comparison and a geographical review by classifying marine accidents involving the entanglement of marine litter by statistical agency, type of vessel, floating substance, and the season. Through this, the characteristics for each standard will not only provide the grounds for identifying the locations at which marine accidents involving entanglement of marine litter frequently occur, but also will derive meaningful results for marine accident statistics and their management.

In this context, the rest of this paper is organized as follows: Section 2 represents statistical analysis of marine accidents caused by entanglement of marine litter in Republic of Korea. Section 3 includes ArcGIS based geographical analysis of the accident. Session 4 analyzes the conditions of multiple accident areas based on facilities of fisheries and leisure. Sections 5 suggests future technical countermeasures for marine accidents caused by entanglement of marine litter and Section 6 concludes the paper.

2. Statistical analysis of marine accidents caused by entanglement of marine litter by classification criteria

2.1. Standard for the statistical agency

2.1.1. Korea Maritime Safety Tribunal

The Korea Maritime Safety Tribunal (KMST), which is affiliated with the Ministry of Oceans and Fisheries, is an agency in charge of investigating and adjudicating on marine accidents, which classified the marine accidents caused by floating marine litter as “safety hindrance accidents” until 2017. Since 2018, however, it has used the term “marine accidents involving entanglement of marine litter.” Marine accidents involving entanglement of marine litter are defined as those in which a vessel “cannot sail since the propeller is entangled by floating marine litter such as discarded ropes and discarded fishing nets”[14].

In the KMST’s statistics, marine accidents involving the entanglement of marine litter have increased to an average of more than 300 cases, and it is also apparent that their proportion is not small because they account for approximately 11% of marine accidents.

2.1.2. Korea Coast Guard

The Korea Coast Guard (KCG), which is affiliated with the Ministry of Oceans and Fisheries, is an agency which protects the lives of people and vessels in the sea, and searches, rescues, and salvages in dangerous conditions. The KCG publishes an annual statistical report on the maritime disasters and accidents, and has classified the types of maritime disasters and accidents into collision, capsizing, sinking, and fire. It defines marine accidents of entanglement of marine litter as the “cases of the propeller in sail being entangled by floating marine litter such as discarded ropes and fishing nets”[17]. The difference is that the KMST defines the inability to sail due to floating marine litter as a marine accident, while the KCG defines the entanglement itself as a marine disaster and accident.

Until 2013, the KCG had classified marine accidents caused by floating marine litter as “propeller failure” due to negligence in sailing. Thereafter, from 2014 to 2018, the term was changed to “safety impeding accident” and from 2019 became “marine litter entanglement accident.” According to the KCG statistics, marine accidents involving entanglement of marine litter have shown an increase of 400 or more cases on average, accounting for approximately 12% of all marine accidents[17].

Since the data collection process for accidents and the definition of marine accidents vary for the KMST and the KCG according to the role of the agency, the scope of an accident and statistical figures will differ. However, the statistics of the two agencies are such that the accidents of entanglement of marine litter have shown a consistent increase. It is apparent that the relevant type of accident rapidly increased first in 2015, and again in 2019.

2.2. Standard for the vessel type

Since the number of accidents and the scale of damages vary depending on the type of vessel, the type of vessels in marine accidents involving entanglement of marine litter can be broadly classified into fishing vessels and non-fishing vessels based on the KMST’s statistics for the past 5 years, and the type of vessel for which the most accidents occurred has been analyzed specifically. While the number of accidents for both fishing vessels and non-fishing vessels have demonstrated an increasing trend, fishing vessel accidents have a difference of 2 to 10 times compared to non-fishing vessel accidents, and 4.6 times more on average.

2.2.1. Fishing vessels

Fishing vessels can be broadly classified into coastal fishing vessels, offshore fishing vessels, division fishing vessels, fishing vessels and other fishing vessels. When comparing the number of marine accidents involving entanglement of marine litter by vessel type among fishing vessel accidents, coastal fishing vessels demonstrated the largest frequency of incidence, followed by offshore fishing vessels and then by fishing vessels. Coastal fishing vessels have sustained over 100 accidents since 2016, and this figure has consistently increased, with over 150 accidents in 2020. While the trend of accidents involving offshore fishing vessels is not constant given the repeated increases and decreases, it has shown an average of 77, which is not small at all.

There are an average of 32 marine accidents involving the entanglement of marine litter per year for fishing vessels. Numerically speaking, it may be determined that the rate of incidence is lower than that of the coastal fishing vessels and offshore fishing vessels, yet looking at the current status of the fishing vessel industry over the past 10 years according to the Fishery Resources Policy Division of the Ministry of Oceans and Fisheries, the number of vessels reported for the fishing vessel industry has been fairly constant, without any significant change. On the other hand, the number of users of fishing vessels has increased significantly since 2015 in connection with the hobbies of the general public. If floating marine litter are entangled with the propeller of fishing vessels and this leads a boat to capsize, casualties may result for the users of the fishing vessels, and thus this is an area which should never be overlooked.

2.2.2. Non-fishing vessels

In the KMST's statistics, non-fishing vessels may be classified into passenger vessels, cargo vessels, oil tankers, tugs, water leisure equipment, and other vessels excluding fishing vessels. Passenger vessels include general passenger vessels, car ferry passenger vessels, high speed passenger vessels, and pilot vessels with 13 or more passengers, whereas cargo vessels include general cargo vessels, car ferry cargo vessels, automobile carriers, refrigeration carriers, container carriers, etc. Oil tankers include crude oil carriers, liquefied natural gas carriers, liquefied petroleum gas carriers, and oil tankers, and tugboats include port entry tugs, towing tugs, and berthing tugs. Furthermore, water leisure equipment includes motorboats, sailing yachts, hovercraft, and surface flying vessels, and other vessels include barges, dredgers, test survey vessels, and pilot vessels with less than 13 passengers, etc.

As for marine accidents involving the entanglement of marine litter of non-fishing vessels, water leisure equipment has accounted for an overwhelmingly significant proportion compared to other types of vessels. As with fishing vessels, water leisure equipment is involved with marine sport as well as hobbies and the leisure life of the public, and as such, caution needs to be taken not to cause casualties due to marine accidents involving the entanglement of marine litter. As for other non-fishing vessels, such as passenger vessels, oil tankers, cargo vessels, tugboats, and other vessels, it was observed that less than 10 accident have occurred each year.

2.3. Standard for floating substances

Considering the inflows of the goods used on land and the types of the goods used in the sea alone, floating substances existing in the sea are very diverse. In understanding the causes of marine accidents involving entanglement of marine litter, the key issue would be to analyze which floating substances cause accidents and which floating substances are the most common. Accordingly, as a result of surveying and examining the floating substances which have caused the marine accidents involving entanglement of marine litter based on the KMST's statistics for the past 5 years, discarded fishing nets, ropes, fish traps, anchors, seaweeds, tents, etc. were confirmed. The marine accidents involving entanglement of marine litter were analyzed by further classifying into fishing gear (auxiliary parts), marine organisms, other and the unknown, excluding fishing nets, cordage (ropes or wires), and fishing nets and lines. Among the marine accidents involving entanglement of marine litter which occur each year, those caused by fishing nets and cordage account for the largest share. Over 200 accidents caused by fishing nets have occurred since 2019, while over 100 accidents caused by cordage have occurred since 2019.

2.3.1. Fishing net

The types of fishing nets, which are the causes of the marine accidents involving entanglement of marine litter, were so diverse that it was difficult to identify a single fishing net used by the vessels, fishing nets used by the farms such as abalone and seaweed, and by the nets. However, it is necessary to verify why such fishing nets exist in the sea, including whether they are abandoned in the sea because they were aged and could no longer be used (discarded), and whether they could not be recovered due to human or administrative negligence (lost). This study compared the patterns for each year by classifying the discarded fishing nets and lost fishing nets concerning the fishing nets, etc. of other farms according to the statistics of the KMST. Over 90% of the fishing nets which caused the accidents turned out to be discarded fishing nets and nets, while fishing nets that were believed to be lost accounted for 10% or less of the marine accidents involving entanglement of marine litter. As such, it was confirmed that most of the fishing nets, which were the largest cause of the marine accidents of entanglement of marine litter, were not brought to the land and instead were discarded in the sea.

2.3.2. Cordage

In the course of vessel operation, various types of ropes and wires are widely used for mooring, anchoring, lifesaving, loading and unloading, and navigation equipment. Based on the KMST's statistics, ropes which caused marine accidents involving the entanglement of marine litter include the ropes used for anchoring or mooring vessels, ropes for towing vessels, ropes used for fish farming or fishing gears for fishing, wires, fishing lines, etc.

2.3.3. Fishing gear (auxiliary part)

The auxiliary parts of the fishing gear which caused marine accidents involving the entanglement of marine litter were often sea anchors. A sea anchor is a device which is used for operation or is used when small survey boats wish to maintain a constant position but when it is difficult to lower the sail to the seabed due to the deep water. However, this also consists of ropes and tents, and thus if it remains in the sea as floating material, it becomes entangled with the propeller of another vessel and causes an accident.

2.3.4. Marine organisms and others

While there are cases in which marine accidents occur due to factors of the aquatic ecosystem and natural environment such as marine algae including gulfweed, seaweed fusiforme, and seaweed, as well as aquat-

Table 1. Current Status of the Rate of Incidence of Marine Accidents Involving Entanglement of Marine Litter by Season

Unit: Cases, %

	2016		2017		2018		2019		2020		2016-2020
	No. of cases	Ratio	No. of cases	Ratio	No. of cases	Ratio	No. of cases	Ratio	No. of cases	Ratio	Average ratio
Spring	63	22.5	69	22.2	67	24.1	79	22.8	80	22.2	22.7
Summer	69	24.6	84	27.0	64	23.0	92	26.5	88	24.4	25.1
Fall	87	31.1	86	27.7	89	32.0	95	27.4	113	31.3	29.9
Winter	61	21.8	72	23.2	58	20.9	81	23.3	80	22.2	22.3
Total	280	100	311	100	278	100	347	100	361	100	100

Reference: Korea Maritime Safety Tribunal[14]

ic objects, they are extremely rare. Other substances include litter from planes or wooden blocks used for ports and vessels, rubber, waste tires, tents, vinyls, tapes, PVC hoses, various litter, etc. Furthermore, 62 such cases have occurred over the past 5 years, including accidents caused by unknown substances which were difficult to be identified.

2.4. Standard for the season

Since marine litter are the product of human life, various socio-economic and institutional factors such as vacation season, outing, fishing season and non-fishing season, and marine traffic also affect the quantity of the marine litter generated. Comparing the marine accidents involving entanglement of marine litter by season over the last 5 years, the largest number occurred during fall, accounting for 30% on average. Other accidents which occurred in spring, summer and winter occurred at a similar rate of approximately 22~25% in Table 1[14].

In addition to the above criteria, statistics classified as the East Sea, the West Sea, and the South Sea of Korea can be expected in consideration of the impact of the ocean current. Ocean current can make gyre which create plastic accumulation zone(GPGP)[18]. In fact, the Republic of Korea is affected by garbage flowing from China in winter[19,20]. However, it is not appropriate for the purpose of this study because it takes into account foreign marine waste by ocean currents. Actually, when the accident location was classified and investigated by coast in this study, it was difficult to confirm a clear difference.

3. ArcGIS based geographical analysis of marine accidents caused by entanglement of marine litter

GIS analysis is used in various fields as a useful method for grasping the impact of geographical location and specific environment[21,22]. In particular, it is used not only for research on the occurrence of marine accidents[23,24]. but also for research on accidents of other means of transportation[25,26]. The results of a geographical review of the marine accidents involving entanglement of marine litter may help identify the location of key frequency of related accidents and may also be considered as a port or route to support the safe navigation of vessels[27,28]. Therefore, this study has utilized the ArcGIS program, which supports decision-making[29] by integrating and managing the geographic location information and data closely related to human life[30,31].

Thus, the location information of latitude and longitude of the marine accidents involving the entanglement of marine litter was reflected in the GIS in the form of points by using the statistical data of the KMST. However, it is difficult to visually identify multiple locations by reflecting the location information of accidents which include over 300 cases per year only in the form of points. Thus, by calculating the density, a density map was structured from which an accident high density area could be derived. The density map was set to be represented in the order of red, orange and yellow as the density of accidents increased, and the low-density area was represented in green.

3.1. Overall accidents

By reflecting the location information of the accidents which occurred during the last 10 years based on the KMST's statistics in the GIS, it was apparent that the largest number occurred off the coast of Incheon, as well as the coasts surrounding Busan and Jeju-si, and Geoje and Tongyeong were also verified to be frequency locations for the accidents. Meanwhile, through reflecting the statistics of the KCG in the GIS, it was verified that Incheon was the most frequent location for the accidents, and Busan also turned out to be a highly frequency location for the accidents. Hence, Incheon and Busan were the common high-frequency locations for the accidents, which reflects the location information of the marine accidents of entanglement of marine litter provided by the KMST and the KCG in Figure 1.

3.2. Accidents by type of vessel

By structuring the density map for each type of vessel based on KMST's statistics, the highest frequency location for fishing vessel accidents was found to be the coast of Jeju-si, and Geoje, Tongyeong and Incheon also turned out to be high-frequency locations. Furthermore, the highest frequency location for accidents of non-fishing vessels such as passenger vessels, cargo vessels and tugboats turned out to be the coasts of Incheon and Busan. As such, there is a clear difference between fishing and non-fishing vessels in the frequency of accidents in Figure 2.

3.3. Accidents by floating marine litter type

Since most of the floating marine litter which have caused marine accidents involving entanglement of marine litter were fishing nets and cordage, a density map was structured using the location information of accidents caused by fishing nets and cordage based on the information on marine accidents involving the entanglement of marine

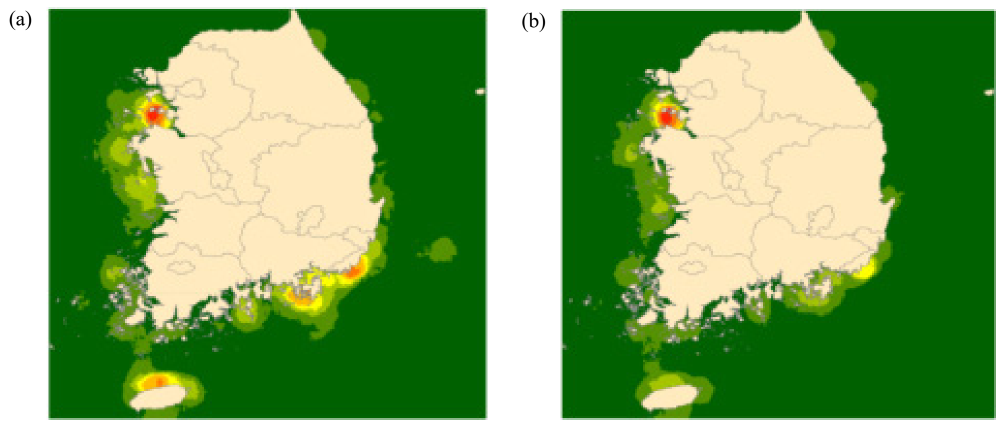

Figure 1. Density map of marine litter entanglement accidents for Korea Maritime Safety Tribunal (a), and for Korea Coast Guard (b).

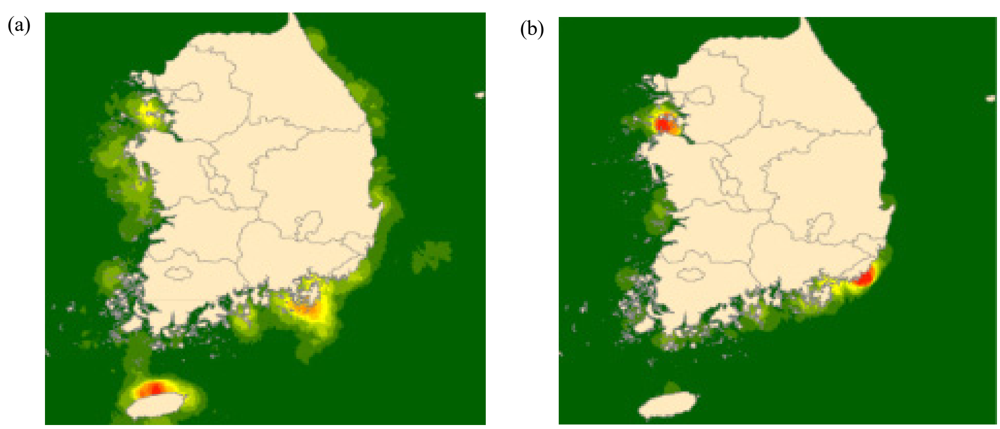

Figure 2. Density map of marine litter entanglement accidents for fishing vessel (a), and for Non-fishing vessel (b).

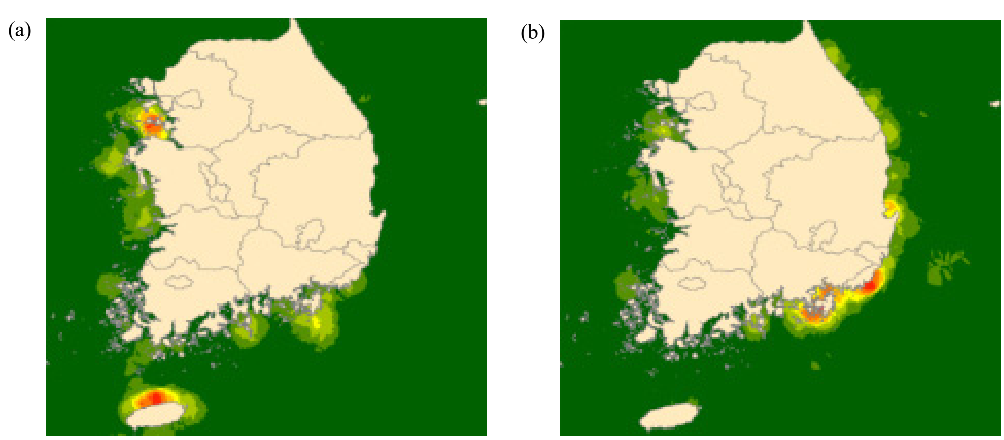

Figure 3. Density map of marine litter entanglement accidents by fishing net (a), and by cordage (b).

litter provided by the KMST.

The waters in which accidents caused by fishing nets occurred most frequently were off the coast of Jeju-si, followed by Incheon, Geoje and Tongyeong. Furthermore, accidents involving cordage occurred most frequently off the coasts of Busan, Geoje and Tongyeong, and the coast of Pohang was another location where cordage-caused accidents have frequently occurred in Figure 3.

The key characteristic is the fact that marine accidents involving entanglement of marine litter by fishing nets and marine accidents involving entanglement of marine litter by fishing vessels are similar in terms of the density map and high-frequency locations for accidents. While fishing vessels and fishing nets have the common denominator of fishing, considering the location of fishing farms and fishing grounds across all three sides of Korea, a relevant analysis is needed since it may be inferred that there are many fishing nets that are discarded or lost in the process of the fishing vessels' operation. Furthermore, there is a clear difference between a high-frequency location for marine accidents, which are caused by fishing nets, and a

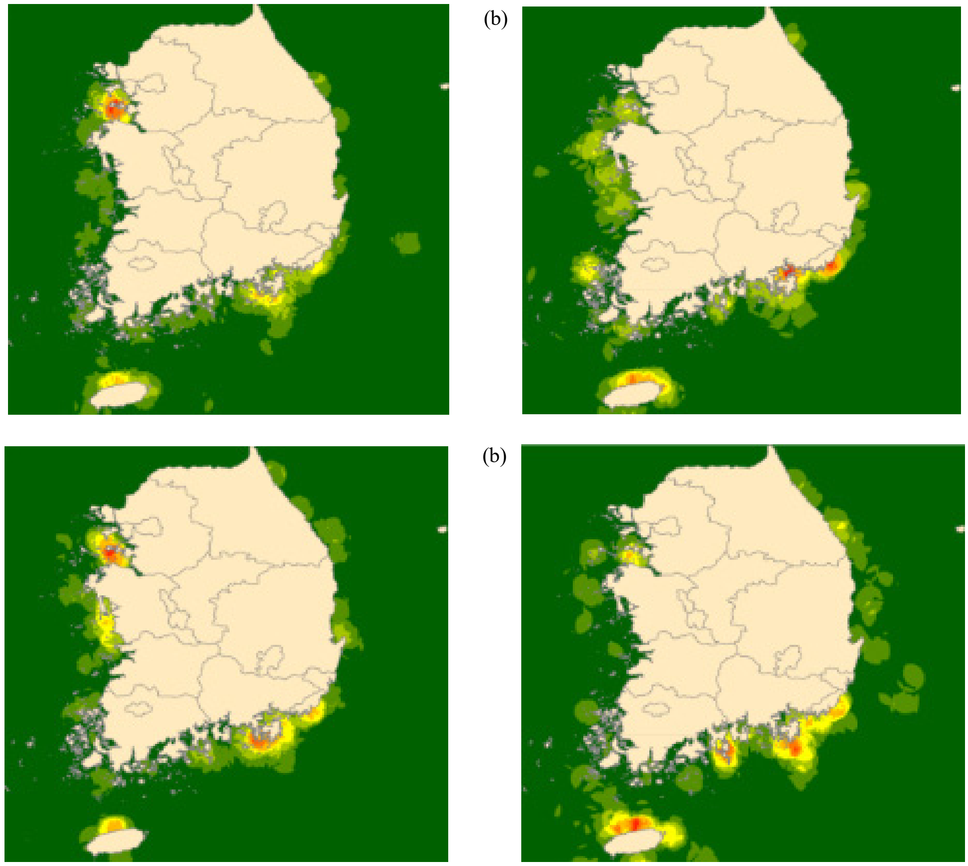

Figure 4. Density map of marine litter entanglement accidents for spring (a), for summer (b), for fall (c) and for winter (d).

high-frequency location for marine accidents, which are caused by cordage, and it will be necessary to review the information on the occurrence of marine plastic litter, etc.

3.4. Accidents by season

The highest frequency location for accidents in the spring was the waters of Incheon (secondary location of high incidence: Jeju-si, Geoje and Tongyeong, and Busan), and during the summer, the highest rates of incidence were found in Busan, Geoje and Tongyeong (secondary location of high incidence: Jeju-si and Mokpo). During the fall, the highest frequency location for accidents turned out to be Incheon, Geoje and Tongyeong (secondary location of high incidence: Jeju-si, Busan, and Taean-gun), and during the winter, it turned out to be Tongyeong and Geoje, Yeosu and Jeju-si (secondary location of high incidence: Busan and Incheon). The high-frequency locations for accidents by season turned out to be Incheon, Busan, Tongyeong and Geoje, Jeju-si, etc., which were similar in Figure 4.

The marine accidents involving entanglement of marine litter were the second most common type of marine accidents following the marine accidents caused by engine damages. By type of vessel, the proportion of the accidents of fishing vessels was higher than that of the non-fishing vessels, and while they occurred a great deal during the fall in terms of the season, there was no significant difference. Most of the accidents occurred during the daytime from 08:00 until 16:00 rather than during the night time, when the visibility was mediocre at best.

When comparing the figures by incorporating such standards as the type of vessel, floating marine litter, and the season, the probability of accidents caused by fishing nets was higher than those caused by cordage by 50% or more for fishing vessels, and while the probability of accidents by season was generally similar, such accidents were more likely to occur during the fall than during the other seasons. Non-fishing vessels such as tugs, oil tankers, cargo vessels, leisure equipments, and passenger vessels have a similar probability of being entangled by fishing nets and cordage, and seasonally speaking, the probability of accidents occurring during the fall turned out to be twice that of the winter. In terms of floating marine litter, it was also observed that the accidents caused by fishing nets and cordage also occurred more frequently during fall than during the other seasons in Table 2[14].

Notwithstanding the fact that the marine accidents involving entanglement of marine litter have occurred most often for the fishing vessels, the important point to note and consider is marine leisure activities related to the public's hobbies and leisure activities. In this area, marine accidents involving entanglement of marine litter for fishing vessels and water leisure equipment have increased each year, and efforts to reduce human casualties will be required accordingly.

This study has reflected the location information of the marine accidents of entanglement of marine litter based on the statistical agency

Table 2. Comparison of the Number of Cases of the Marine Accidents Involving Entanglement of Marine Litter by Standard

Unit: Case

	Floating marine litter (fishing net)	Floating marine litter (cordage)	Season (Spring)	Season (Summer)	Season (Fall)	Season (Winter)
Type of vessel (fishing vessel)	771	415	279	310	368	303
Type of vessel (non-fishing vessel)	137	141	79	87	102	48
Floating marine litter (fishing net)	-	-	207	239	264	198
Floating marine litter (cordage)	-	-	130	134	171	121

Reference: Korea Maritime Safety Tribunal[14]

Table 3. Location of High Incidence for the Marine Accidents of Entanglement of Marine Litter by Standard

Criteria for Classification	Incheon	Busan	Tongyeong and Geoje	Jeju-si	Taean-gun	Pohang	Mokpo	Yeosu
Statistical agency (Korea Maritime Safety Tribunal)	◎	○	○	○				
Statistical agency (Korea Coast Guard)	◎	○	○					
Type of vessel (fishing vessel)	○		○	◎				
Type of vessel (non-fishing vessel)	◎	◎						
Floating marine litter (fishing net)	○		○	◎				
Floating marine litter (cordage)		◎	◎			○		
Season (Spring)	◎	○	○	○				
Season (Summer)		◎	◎	○			○	
Season (Fall)	◎	○	◎	○	○			
Season (Winter)	○	○	◎	◎				◎

◎ Primary location of high incidence, ○ Secondary location of high incidence

(KMST, KCG), type of vessel (fishing vessel, non-fishing vessel), floating marine litter (fishing net, cordage), and four seasons in the GIS program and reviewed the geography and analyzed high-frequency locations. Consequently, as a result of comprehensively reviewing the results of the geographic reflection by standard, the key high-frequency locations for the marine accidents of entanglement of marine litter in Korea were found to be Incheon, Tongyeong and Geoje, Busan and Jeju-si (northern waters of Jeju-do) as illustrated in Table 3.

4. ArcGIS based condition analysis of mutiple accident areas by entanglement of marine plastics

The analysis of the accident-related statistics and the relevant location information raises questions about the reason as to why accidents have occurred more geographically in Incheon, Tongyeong and Geoje, Busan and Jeju-si(northern waters of Jeju-do). To find the answer to this question, this study analyzed the association of the traffic of the ports surrounding the high-frequency locations for accidents[32,33], the size of the fishing farms and grounds[34], boarding areas for leisure equipment and routes of yachts, and the marina ports[35] in ArcGIS.

4.1. Traffic volume of the Port

4.1.1. Outbound vessels

This study has surveyed the volume of outbound traffic for 10 years from 2010 to 2019, focusing on Busan, Incheon, Geoje and Tongyeong, where many accidents involving the entanglement of marine plastic litter have occurred. Busan turned out to be the port with the highest outbound traffic among the ports in Korea, and Incheon was also among the ports with the highest outbound traffic. Meanwhile, Geoje was in middle tier for handling traffic for outbound vessels, while Tongyeong was in low tier for handling the same.

4.1.2. Inbound vessels

As with the traffic of outbound vessels, this study surveyed the inbound traffic for 10 years from 2010 to 2019, focusing on Busan, Incheon, Geoje and Tongyeong. In terms of the inbound traffic, Incheon ranked higher than Busan. Busan was ranked the highest in terms of handling the outbound traffic, yet for inbound vessels, it was handling the traffic in middle to top tier. Meanwhile, Geoje and Tongyeong handled the traffic for the inbound vessels in middle to low tier, similar to its level of handling outbound traffic.

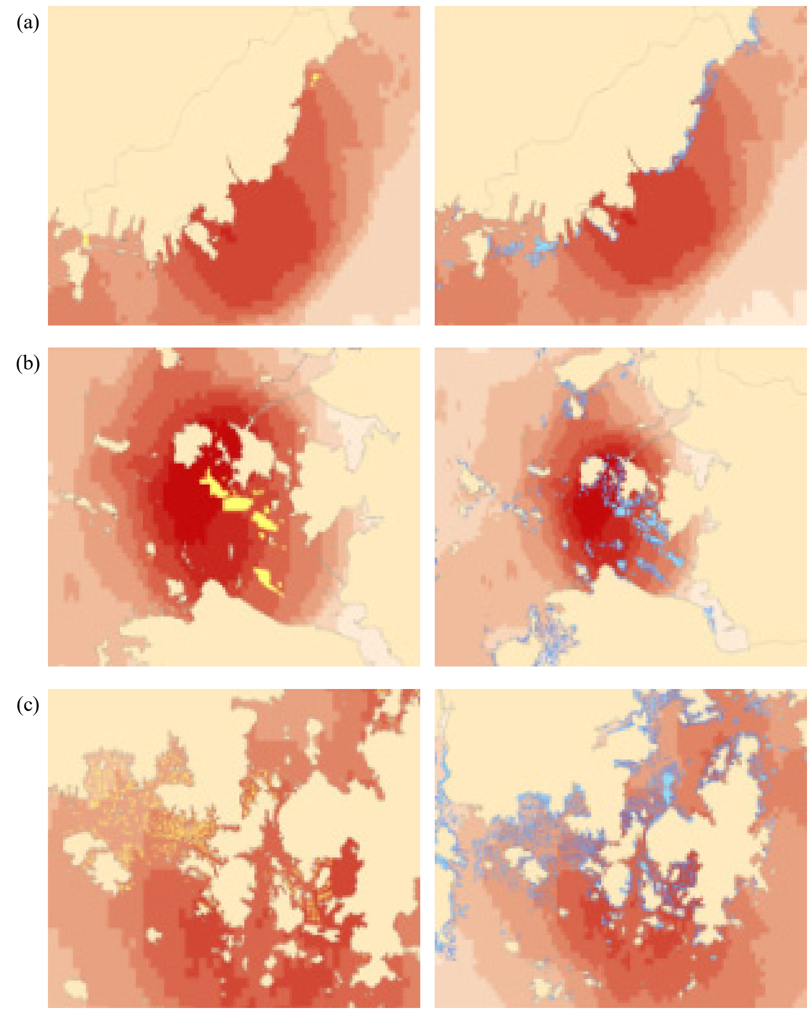

Figure 5. Comparison of the Locations of fishing farms and grounds for Busan (a), for Incheon (b), and for Geoje and Tongyeong (c).

4.2. Fishing farms and grounds

A fishing farm is a place where facilities are installed for artificially cultivating and harvesting marine animals and plants, such as fish, shellfish, and seaweed, in the sea or river, by dividing a certain water surface and using the bottom of the water surface, or installing the required facilities in the water to conduct farming. Furthermore, fishing grounds act as information on village fishing, farming fishing, and fixed shore net fishing off the coast of Korea[33]. In this study, the location information on the fishing farms and grounds was compared and analyzed by reflecting the data from around Busan, Incheon, Geoje and Tongyeong in the GIS from marine spatial information of the Korea Hydrographic and Oceanographic Agency's Open Sea in Figure 5. The darker red it is, the more marine accidents have occurred, while yellow signifies the location of farms, and blue the location of fishing grounds. As for Busan, the fishing farms and grounds were not located around the area where there were marine accidents involving entanglement, and Incheon was partially located near the area where there were marine accidents involving entanglement. Meanwhile, for Geoje and Tongyeong, many extensive farms and fisheries were located around the area.

4.3. Leisure equipment boarding area, yachts' route and marina port

This study compared the differences between the high-frequency locations for accidents by reflecting the information on the boarding area of leisure equipment around the beach and the location of the route of yachts for leisure activities in Figure 6 by considering the fact that the number of marine accidents involving the entanglement of leisure equipment has continuously increased.

In Busan, the leisure equipment boarding area was located near the area with high-frequency locations for marine accidents involving entanglement, and the yachts' route was formed in the manner of crossing the high-frequency location for accidents. Meanwhile, in Incheon, the leisure equipments' boarding area is located a somewhat short distance from the location with a high-frequency of accidents, yet as with Busan, the yachts' route was structured in the form where they were entering and exiting the high-frequency locations. For Geoje and Tongyeong, it would also be difficult to think that the boarding area is located near the high-frequency location for accidents, but it was apparent the yacht's route is located in the high-frequency location for accidents. Note 1: The darker red it is, the more marine accidents have occurred, while blue dots signify the location of the leisure equipments'

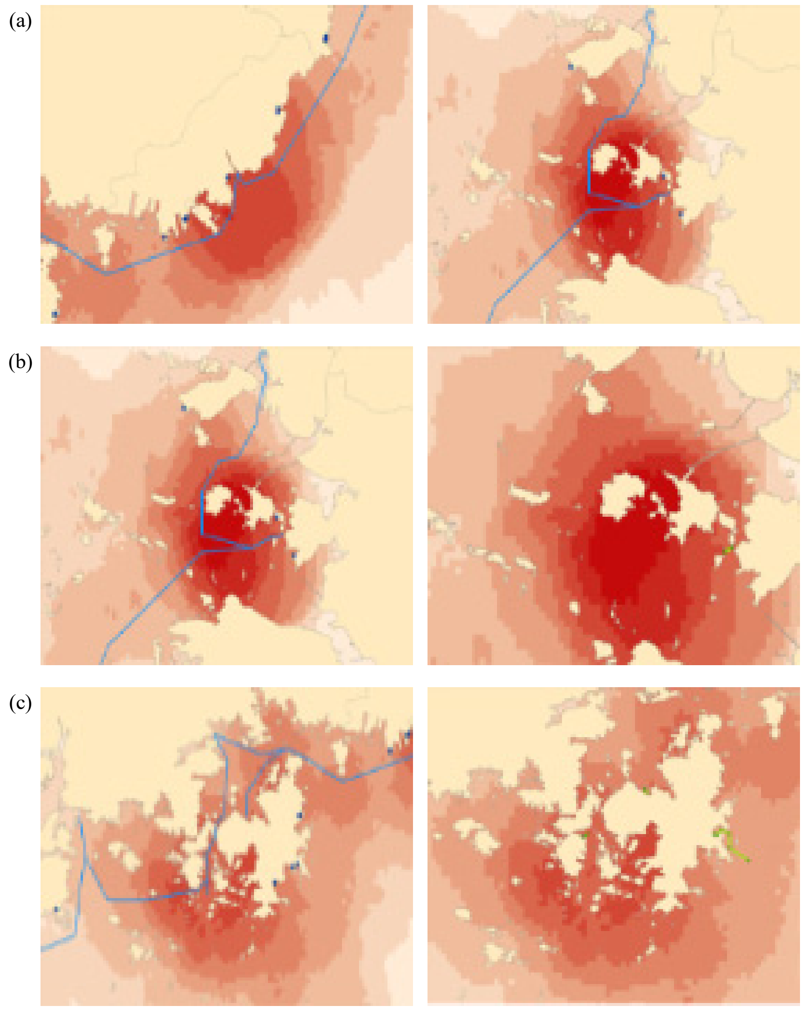

Figure 6. Comparison of the Locations of the Leisure Equipments' Boarding Area, Yachts' Route and Marina Port for Busan (a), for Incheon (b), and for Geoje and Tongyeong (c).

boarding area, and the blue lines, the yachts' route.

A marina port is a port equipped with berthing facilities and mooring for yachts and leisure boats, coastal walks, shops, restaurants, accommodation facilities, etc. in accordance with Subparagraph 1 of Article 10 of the Act on the Development, Management, Etc. of Marinas[36]. Based on the location of the marina ports, and as a result of verifying the high-frequency locations for the marine accidents involving entanglement such as Busan, Incheon, Geoje and Tongyeong, it was confirmed that there are common marina ports around the high-frequency locations of accidents. Note 2: The darker red it is, the more marine accidents have occurred, while green dots signify the location of marina ports, and green lines, the location of yacht routes.

5. Future technical countermeasures for marine accidents caused by entanglement of marine litter

5.1. Improvement of the existing technology

5.1.1. Rope cutter

The rope cutting device (rope cutter) plays a role in preventing the contamination of fishing nets, ropes and others with a view to preventing the entanglement of and damages to the propeller and shaft system. This device has different characteristics depending on the type, and a different operation process depending on the structure (shape of scissors, disk, and shaver, etc.). The scissor-type device was first released in the relevant market and consists of a rotary cutting device fixed on the propeller and two or more blades, which rotate and deliver shearing force, while the blades of the cutter rotate in conjunction with the propulsion shaft, thereby cutting the cordage as the fixed blades operate like scissors. This provides a significantly high level of effectiveness for substances such as ropes, nets, and plastic sheets[37]. The disk shape takes on a structure wherein a thin stainless steel disk with a sharp edge cuts the ropes, and as for the feature of the structure, if and when a floating marine litter exceeding the diameter of the cutter's blade is entangled, the cutting ability will decline, and thus its usefulness will be restricted. Furthermore, the shaver type includes the vertically fixed blades at a fixed position, and while the blades rotate, the cordage and other substances may be continuously cut like a shaver, yet the installation is quite complex and difficult.

Since the rope cutting device operates for the purposes of enabling the vessel to continue to sail by cutting off the large marine plastic entangled around the propulsion shaft, floating marine litter such as fishing nets and ropes which were entangled still exist in the marine environment after cutting them out, and may cause re-entanglement, which means that it is not a fundamental solution in the long term. As such, it is necessary to improve the function of the rope cutting device to ensure that the floating substances may be recovered after cutting them out as well as verifying the effectiveness according to the difference in terms of the size, type of vessel, model of vessel, navigation area, type and shape of the floating substances, etc.

5.1.2. Rope guard

The rope protective device (or rope guard) is a facility designed to fundamentally prevent the entanglement of ropes and nets itself with the propeller, and is a passive method since it does not have a cutting function like a rope cutting device. For that reason, there are many types which are mainly combined with a rope cutting device, and yet the ME manufacturers do not prefer their installation given the concerns over reduced efficiency, such as the loss of propulsion. Furthermore, the rope or floating substances of the net may be entangled with the rope protection device itself. If any floating substances are entangled with the rope protective device, not only will damages be incurred to the device but also the hull vibration may increase, which may further cause a situation where it will be even more difficult to cut than when a rope cutting device is available. In addition, while this method is applicable for low speed vessels around 10 knots, there is a limitation in that it is difficult to apply to high speed vessels at or above 20 knots[38]. The rope protective device also requires validation of the effectiveness of various conditions, and it ought to be developed to ensure that it can be improved, including the function of the floating marine litter recovery.

5.2. Research and development projects(R&D) required in the future

Many accidents have occurred with fishing vessels during offshore fishing, and if the propeller at the bottom of the vessel is entangled with fishing nets or ropes, crew members on board or divers on land must be hired to remove them manually. However, the process of removing large floating marine plastic litter can not only incur operation delay and costs such as divers' allowance but can also result in human casualties including death.

Developed as a means to help prevent human casualties under unpredictable underwater conditions and conduct seabed searches, the use of an underwater robot to remove entangled large marine plastics may be considered as a means to overcome the limitations of the rope cutting device and the rope protective device. However, fishing vessels which experience the most accidents involving the entanglement of marine litter are loaded with the catch and fishing gears, and the area for sailors is not wide, and in its current state of development the underwater robot is rather large. In addition, it is necessary to resolve the problem of cost for the dissemination of technology following commercialization. Considering the size of each type of fishing vessel, it is necessary to develop, validate the technologies of, and supply a small underwater robot which can confirm, remove, and recover the entangled substances.

6. Conclusion

Marine accidents involving the entanglement of marine litter have continued to increase, with over 300 to 400 cases per year according to the statistical agency. Depending on the situation, entanglement of marine litter may also lead to large-scale marine accidents which cause capsizing and sinking, thereby further causing detrimental casualties and material damages, and thus exceptional attention and care is required. In this study, Incheon, Busan, and Geoje and Tongyeong were found to be the multiple accident areas considering the location information by standards such as the statistical agency, type of vessel, and floating substance.

The analysis was focused on information on the traffic of the surrounding ports, fishing farms and fishing grounds, leisure equipments' boarding area, yacht's route and marina ports. The areas were coastal cities where fishing facilities or leisure culture related conditions were activated, with the port which handles much traffic of outbound and inbounds vessels located nearby.

Marine environmental pollution (marine plastic pollution) impacts not only the marine ecosystem and food chain, but also the hull and engine of ships, and may further pose threats to the safety of vessels and crews. For this reason, it ought to be addressed with a sense of urgency from the perspective of vessel operation. For vessel operators, particular attention is required when operating in the areas above, and the dissemination of technology and the convenience of application for securing safety should be achieved. Furthermore, it is necessary to find a common link through the field investigation and statistical analysis of the relevant areas, and to strive to remove the root causes of marine accidents involving entanglement of marine litter by reducing marine litter. Furthermore, it is necessary to confirm whether the reason for the different locations of high-frequency accidents by standard (type of vessel, floating marine litter, season, etc.) is related to the characteristics of the time period, such as whether fishing is allowed or prohibited, and the public leisure culture or travel related trend depending on the season.

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