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The drift lighter project — Estimation of drifting range and source of North Pacific marine litter using disposable lighters washed up on coasts

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ABSTRACT

Disposable lighters are one of the few types of marine litter that have evidence of their source, because they have printed information about the consuming country or city (e.g., point of sale address or telephone number). Lighters were used to estimate the flow, source, and drifting range of marine litter in the North Pacific. From August 1998 to February 2015, 79,948 lighters were collected from 1,661 sites on the beaches and river estuaries in Japan, Taiwan, Korea, Russia, China, Hawaii, and the west coast of North America. This method clarified that the lighters runoff from river basin to the ocean through rivers. From the distribution of outflow areas, the flow of the lighter was consistent with the ocean currents around East Asia and in the North Pacific. The origins in the North Pacific of the lighter were mainly found to be the coastal areas of East Asia, especially Taiwan, China (between Hong Kong and Shanghai), South Korea, and Japan (Pacific coast side). Furthermore, by monitoring ML using the lighter that can identify source areas, it was shown that it is possible to trace back to the source areas and causes of massive drifts, and to help properly dealing with this contamination issue.

1. Introduction

Marine litter (hereinafter referred to as ML) accumulation is caused by several highly complicated factors. Determining the causes, source, flow, seasonal changes, and drifting range of ML to find a solution to the ML issue is essential. However, since most ML do not have information such as discharge area, date, and cause, and few of them are uniformly discharged from a wide area, the means to directly investigate these issues using ML are limited. Accordingly, a direct and wide-area surveys method must be developed to monitor the source areas, flows, and drifting range using ML.

Traditionally, drift bottles (Hachey, 1935; Kasahara, 1957; Gast, 1966; Fujimoto and Hirano, 1972; Takizawa and Aota, 1978; Otsuka and Ishino, 1988; Nichols, 2005), drift cards (Fry, 1956; Sawanishi and Tomosada, 1968; Heath, 1969; Shirouzu, 1974; Koseki, 1977; Takizawa and Aota, 1978; Kimura et al., 1992), and pumice from submarine volcanoes (Seki, 1927; Nakano and Kawanabe, 1992; Yoshida et al., 2022) were used as means to track ocean currents or study how pollutants or other materials travel through the world's oceans. These studies have used drifted materials with known discharge locations and timing. On the other hand, if the ML has detailed information on the source areas, it is possible not only to directly identify the source but also to trace the factors and timing of the outflow. Around Japan, printer ink cartridges (Yuhi et al., 2008), floating golf balls (Fujieda, 2009a), syringes (Fujieda, 1999), business cards (Fujieda, 1999), beverage bottles (Fujieda, 1999; Yamaguchi, 2000; Okano et al., 2011), and fishing gears (oyster pipes and floats) (Fujieda, 2005, 2009b, 2011; Okano and Kato, 2013; Fujieda, 2014) have been used to identify the ML source. However, printer ink cartridges that spilled from containers on liners in marine accidents are temporary, and floating golf balls are used only at driving ranges where golfers hit into ponds in limited areas of Japan. Although business cards have detailed location information, such as a personal address, plastic cards are rare. Additionally, syringes can only be found in small quantities and are dangerous to handle. Many plastic fishing buoys/floats can be found on beaches, but even if we know the country of manufacture, the sea area where these were used is unknown. Plastic beverage bottles (Ryan, 2019, 2020) are widely utilized across the world, but while the manufactured country can be identified, the detailed city where they were consumed cannot. Studies are also being conducted to clarify its behavior by using floating objects whose location can be determined (Ishii and Michida, 1996; Matsuno et al., 2006; Chang et al., 2008; Kako et al., 2010). In addition, modeling studies for specific drifts (Meguro et al., 2006; Yoon et al., 2010) were also applied to understand this, but, even if the

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Fig. 1. Disposable lighters with store address and phone number were printed by local characters on the body (From left, Korea, Japan, Taiwan, China, and Hong Kong).

source of the discharge could be traced from the drifted ashore area by numerical simulation (Kako et al., 2011), it would not provide evidence of the discharge.

Disposable lighters are one of the few ML items that can be used to identify the retailer cities, as not only does the body or bottom contain information (mark or sticker) about the production or consumption region or country, but the store address or store phone number is also printed on the body in local characters (Fig. 1). Fujieda (1999) used this item to investigate the source of mass drifted litter on the western coast of the Satsuma Peninsula, Kagoshima Prefecture in 1998, and the cause was revealed the 1998 Yangtze River flood caused by heavy rain. In 2003, Fujieda et al. (2006) expanded the monitoring region to the entire country of Japan, and "The Drift Lighter Project" was launched as an attempt to identify the source and the flow of ML (Fujieda, 2003, 2005, 2009a,b, 2013, 2014; Fujieda et al., 2006, 2014b, 2015).

Disposable lighters are possibly the best indicator to observe the ML flow because they possess the following characteristics: (1) A disposable lighter is a product that has been widely used globally, centering on smokers, since it was released as a cigarette tool in the 1970s (Japan Smoking Articles Corporate Association, 2005). In 2013, more than 400 million lighters were imported to Japan and sold (from Ministry of Finance Trade Statistics Product Name Code 961310). (2) A disposable lighter can drift a long time on the sea owing to its robust and hollow construction. (3) It can easily be found, picked up, and carried on the beach, because of its bright color and small size. (4) They can be found on many beaches around the world. For instance, in the 2004 International Coastal Cleanup, 40,754 lighters were collected in 59 countries (The Ocean Conservancy, 2005), and in the 2018 International Coastal Cleanup, 1989 lighters were collected in Japan alone (JEAN, 2019). (5) The international transit of lighters is limited because tourists are prohibited from carrying them to other countries on international flights.

In this study, we utilized lighters collected from beaches and river estuaries in the North Pacific (Japan, Taiwan, Korea, Russia, China, Hawaii, and the west coast of North America) to clarify the causes, sources (discharged cities and countries), flow, and drifting range of ML washed ashore on the coasts in the North Pacific. In addition, a method of monitoring ML using disposable lighters is introduced.

2. Materials and methods

2.1. Sampling and sites

A lighter collection was requested from the local coordinators of the "International Coastal Cleanup" in the North Pacific region (Japan, South Korea, Taiwan, Midway Atoll, Hawaiian Islands, and the west coast of North America) and beachcombers belonging to the Japan Driftological Society via newsletters, websites, and mailing lists. The lighter collection period lasted from August 1998 to February 2015. A total of 79,948 lighters were collected from 1661 sites (beaches and river estuaries) in East Asia (Japan, Taiwan, Korea, Russia, China) and the North Pacific (Hawaii, and the west coast of North America), which stretched over 730 km. At sampling, all drift-ashore lighters on the sites were collected and their coastline length were measured from the map. When a lighter was picked up in a site, the site name, position, date (day/month/year), and beach length were recorded. Additionally, if there was liquid in the tank, a hole was drilled by a power drill with a 2.0 mm bit to remove the gas from the tank before transporting it to the laboratory. Fig. 2 shows the collection sites and Table 1 provides a sampling overview of the collected disposable lighters. In the following text, the collection sites are indicated by the codes shown in Fig. 2. The coastal area was classified into 75 coastal areas (i.e., 33 on the mainland based on prefectures, 24

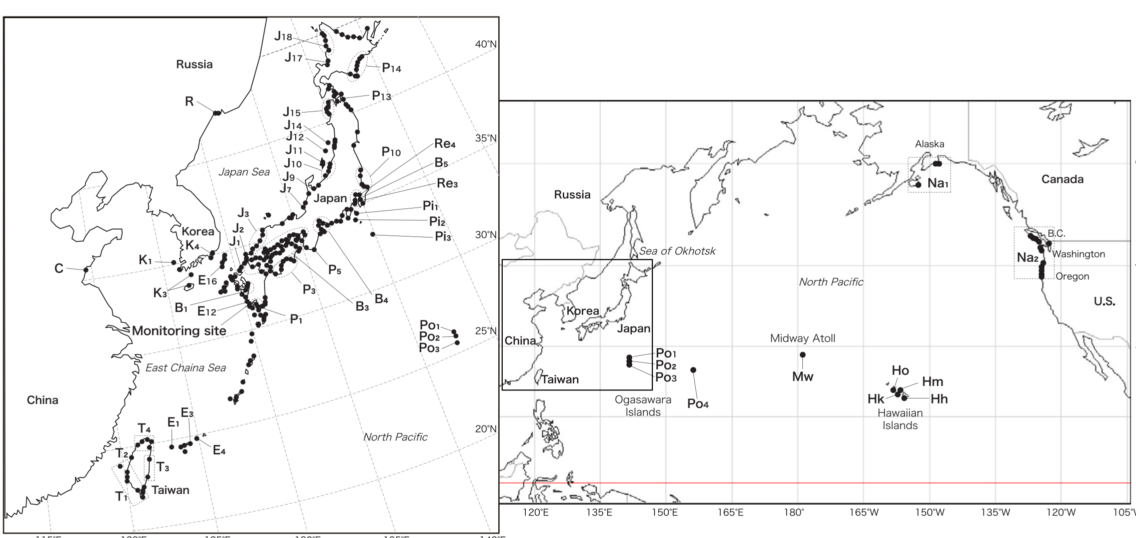

Fig. 2. Sampling sites (•) and a monitoring site of the disposable lighters on the coasts of the North Pacific.

Table 1
Sampling overview of the collected disposable lighters.

No.	Country	Sea area	Category	Code name	Number of sites	Total distance (m)	Drift-ashore density(med) (Lighters/100 m)	Source Region Japanese lighter	Taiwanese lighter	Korean lighter	Chines lighter	Russian lighter	North American lighter	Unclear	Total	Source area Total
1	Japan	East China Sea	Island	E1	40	24,450	7.6	449	421	132	238	0	0	735	1,975	217
2			Island	E2	18	2,050	21.3	89	105	36	116	0	0	276	622	76
3			Island	E3	18	10,640	8.9	215	220	60	182	0	0	367	1,044	143
4			Island	E4	1	2,000	8.5	27	40	11	33	0	0	58	169	21
5			Island	E5	3	170	87.5	30	28	13	40	0	0	75	186	15
6			Island	E6	8	2,325	8.2	46	29	16	33	0	0	62	186	30
7			Island	E7	10	2,450	5.9	36	24	16	47	0	0	74	197	24
8			Island	E8	5	11,150	10.0	14	18	15	60	0	0	1,769	1,876	21
9			Island	E9	8	6,000	10.3	49	121	35	217	0	0	166	588	83
10			Island	E10	26	18,450	10.8	374	392	183	642	0	0	2,410	4,001	275
11			Island	E11	3	1,700	9.6	114	64	22	50	0	0	98	348	33
12			Main land	E12	242	337,850	1.4	3,184	868	179	2,464	0	0	3,638	10,333	744
13			Island	E13	6	1,400	16.7	151	12	6	20	0	0	41	230	23
14			Main land	E14	15	870	19.0	172	30	30	63	0	0	107	402	31
15			Island	E15	132	6,570	45.8	897	395	637	1,597	0	0	1,727	5,253	517
16			Island	E16	67	4,880	26.5	245	212	774	1,074	0	0	979	3,284	312
17		Sea of Japan	Main land	J1	22	15,250	11.3	616	29	182	142	0	0	272	1,241	110
18			Main land	J2	27	8,460	27.5	714	83	475	453	1	0	514	2,240	193
19			Main land	J3	13	6,800	9.0	120	21	245	114	0	0	140	640	86
20			Island	J4	10	0	–	116	22	152	136	0	0	111	537	51
21			Main land	J5	2	0	–	15	2	14	2	0	0	4	37	4
22			Main land	J6	12	270	91.7	299	21	275	114	0	0	187	896	84
23			Main land	J7	3	2,800	6.8	121	7	146	45	0	0	59	378	42
24			Main land	J8	1	0	–	92	0	10	14	0	0	15	131	14
25			Main land	J9	4	730	30.9	205	0	2	9	0	0	44	260	16
26			Main land	J10	12	1,300	51.8	691	40	259	144	2	0	255	1,391	105
27			Island	J11	25	2,620	57.0	330	39	481	317	0	0	286	1,453	159
28			Island	J12	3	130	308.0	175	13	94	43	2	0	66	393	27
29			Main land	J13	15	1,070	36.0	851	53	368	298	7	0	473	2,050	135
30			Island	J14	10	2,105	124.0	2,025	123	1003	526	9	0	1,083	4,769	304
31			Main land	J15	6	1,200	64.9	510	34	169	66	0	0	149	928	58
32			Main land	J16	12	2,780	22.1	124	6	60	140	0	0	84	414	31
33			Main land	J17	2	0	–	99	0	1	1	0	0	18	119	4
34			Main land	J18	11	0	–	173	6	53	10	0	0	46	288	18
35		Sea of Ohktuke	Main land	O1	6	8,560	0.3	50	0	3	3	0	0	21	77	11
36			Main land	O2	6	1,600	8.1	150	6	22	13	0	0	52	243	13
37		Pacific Ocean	Main land	P1	17	5,550	12.4	333	60	7	140	0	0	190	730	60
38			Main land	P2	15	2,750	8.0	163	25	7	86	0	0	123	404	26
39			Main land	P3	26	13,150	11.8	994	78	27	97	0	0	202	1,398	89
40			Main land	P4	7	0	–	92	8	2	12	0	0	18	132	4
41			Main land	P5	6	1,150	24.0	190	8	5	36	0	0	47	286	27
42			Main land	P6	6	7,600	8.5	345	15	10	45	0	0	99	514	33
43			Main land	P7	74	6,650	9.0	1,108	22	9	76	0	0	273	1,488	135
44			Main land	P8	7	3,960	2.2	98	0	0	4	0	0	16	118	11
45			Main land	P9	7	1,700	1.2	43	2	0	5	0	0	15	65	7
46			Main land	P10	13	4,330	15.5	1,047	50	41	74	0	0	203	1,415	119
47			Main land	P11	3	800	6.6	45	1	0	1	0	0	2	49	9
48			Main land	P12	3	1,000	1.5	12	1	2	0	0	0	4	19	1
49			Main land	P13	5	3,750	6.8	172	5	42	27	0	0	44	290	31
50			Main land	P14	16	17,500	2.3	543	3	20	24	0	0	77	667	50
51			Island	Pi1	8	1,630	7.8	88	9	4	32	0	0	37	170	18
52			Island	Pi2	6	9,250	6.3	456	59	37	135	0	0	305	992	40
53			Island	Pi3	9	2,500	5.0	65	23	24	65	0	0	98	275	21
54			Island	Po1	1	0	–	257	86	16	21	0	0	115	495	8
55			Island	Po2	19	2,300	4.0	259	99	33	43	0	0	123	557	33
56			Island	Po3	13	1,180	5.9	60	26	14	15	0	0	39	154	20
57			Island	Po4	1	0	–	8	1	2	0	0	0	4	15	1
58		Bay	Main land	B1	3	700	14.9	117	2	0	2	0	0	11	132	17
59			Main land	B2	69	11,700	2.3	329	15	2	59	0	0	188	593	24
60			Main land	B3	267	51,008	9.0	4,678	35	8	134	0	0	633	5,488	347
61			Main land	B4	56	18,780	6.4	1,228	9	3	92	0	0	236	1,568	102
62			Main land	B5	36	8,970	6.9	1,160	22	6	47	0	0	205	1,440	108
63			Main land	B6	3	1,500	19.8	238	5	9	17	0	0	19	288	24
64		River estuary	River estuary	RE1	7	0	–	2,347	28	38	123	0	0	571	3,107	75
65			River estuary	RE2	3	1,600	22.4	263	1	1	6	0	0	34	305	16
66			River estuary	RE3	3	550	27.9	168	0	2	9	0	0	28	207	25
67			River estuary	RE4	10	300	18.0	686	15	1	43	0	0	181	926	85
68			River estuary	RE5	8	410	10.0	33	0	0	2	0	0	1	36	1
69	Korea		Island	K1	1	500	12.6	1	1	32	8	0	0	21	63	12
70			Island	K2	1	200	40.5	0	2	53	5	0	0	21	81	12
71			Island	K3	2	250	89.6	0	21	99	43	0	0	62	225	33
72			Island	K4	6	1,150	12.5	2	3	232	18	0	0	62	317	49
73	China		Main land	C1	1	300	9.3	0	0	0	22	0	0	6	28	4
74	Russia		Main land	R1	4	400	2.8	0	0	0	0	18	0	7	25	0
75	Taiwan		Main land	T1	13	4,900	13.6	18	473	4	20	0	0	194	709	232
76			Main land	T2	2	1,600	0.8	0	11	0	0	0	0	3	14	5
77			Main land	T3	7	1,900	4.3	0	83	0	10	0	0	22	115	28
78			Main land	T4	18	12,314	7.4	14	426	4	112	0	0	215	771	143
79	Hawaiian	Midway Atoll	Island	MW1	3	420	9.0	22	4	1	5	0	0	12	44	5
80	Islands		Ingestion	MW2	7	13,100	4.7	1,219	344	235	195	1	1	912	2,907	269
81		Hawaii	Island	HM	9	3,500	6.4	111	13	14	11	0	133	139	421	38
82			Island	HK	6	3,000	5.5	70	13	6	9	0	67	76	241	28
83			Island	HH	28	6,800	2.4	144	43	23	12	0	68	138	428	27
84			Island	HO	4	2,700	1.0	5	1	0	2	0	18	4	30	1
85	North America	Alaska	Main land	UA	5	400	2.3	0	1	1	1	1	6	2	12	0
86		West Coast of North America	Main land	UNA	13	5,750	0.0	1	0	0	1	0	7	6	15	1
	Total				1661	730,082	77	32,800	5636	7255	11,412	41	300	22,504	79,948	6484

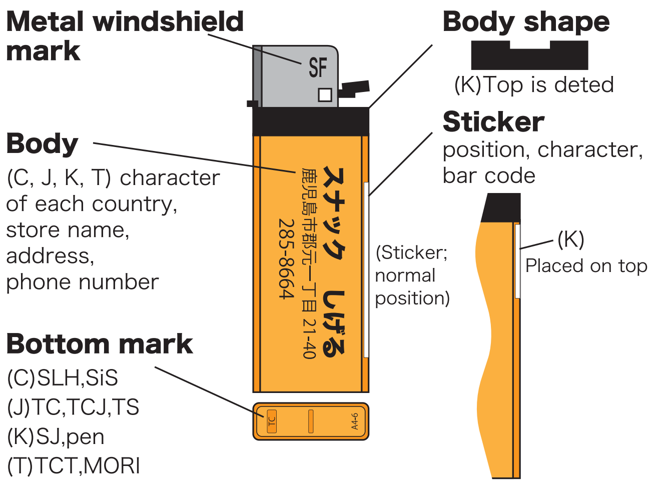

Fig. 3. Determining method of source region (C, China; J, Japan; K, Korea; T, Taiwan) using the bottom mark, body shape, printed character, metal windshield mark, and sticker.

remote islands, six inner bays, and five river estuaries in Japan; 10 coastal areas in the four East Asia countries; six Hawaiian Islands, including Midway Atoll; and two west coasts of the North American continent) and aggregated. In addition, 1 of 2 coasts (1 km) in Washington, USA, 3 of 5 coasts (1.6 km) in Oregon, USA, and 3 of 6 coasts (0.5 km) in British Columbia, Canada, no lighters were found at all. Lighters collected at Midway Atoll were tabulated separately for coast and inland except coast.

2.2. Drift-ashore density

The drift-ashore density was obtained to compare the drifted condition of lighters in each coastal area. The drift-shore density of lighters was calculated using on the number of lighters collected from the coastal area and the collection range (coastline length) and defined as the number of lighters collected per 100 m of coastline length. Furthermore, because the number of samples collected at different times of the year on the same beach can vary by a factor of about 100 (Fujieda, 2014), and because recent cleanup activities are unknown, the period of deposition is not constant, the drift-ashore density for each coastal area is expressed as the median value, not the mean value. The median value of drift-ashore density for each coastal area was calculated for 77 coastal areas for which the densities were reported out of 86 coastal areas.

2.3. Determination of source area and region

Fig. 1 indicates that some lighters have store name, address, and phone number printed on their bodies. Consumers are likely to obtain and dispose lighters in the vicinity of their residence as they are expected to spend the greatest amount of time there (Fujieda, 2013). Therefore, if the store address was printed on the lighter body, then that city was determined as the source area. Also, if the information printed was only a store name and a phone number, then the address was searched using the internet (e.g., Yahoo! loco<https://loco.yahoo.co.jp/>, NAVER <https://www.naver.com/>, Korea phone book <https://www.isuperpage.co.kr/>), and the city of retail store obtained from the text information on the lighter was determined as the source area. We named these "source areas" and presented them as cities.

In contrast, for lighters that did not have identifying information or for which the address could not be determined, the regions and counties of production or consumption was determined using the method shown in Fig. 3, using the printed bar code on the sticker, bottom mark, body shape (Japan Smoking Articles Corporate Association, 2005), and printed characters of each country. The regions and countries of production or consumption were classified into Japan, China, Taiwan, Korea, Russia, North America (including the U.S. and Canada), and others (Philippines and Thailand) (Fujieda, 2003), and we named these "source regions". We recognized the drifting range of ML by source region in the North Pacific on 86 coastal areas using 57,444 lighters for which six source regions was determined. These are referred to here as Japanese lighters, Chinese lighters, Taiwanese lighters, Korean lighters, Russian lighters, North American lighters.

2.4. Verification of land-based spills

It is possible that, due to the lighters' high portability, there is a considerable gap between the location of the store where the lighters were purchased and the place where they were disposed of. Therefore, we collected 4116 lighters from the estuary of four class A rivers in Japan (the Arakawa River Re_4, the Tama River Re_3, the Yodo River, and the Sendai River) from November 2003 to November 2012. Based on the source area distribution of these lighter, we verified the possibility that the lighters flowed out of land areas and through the river into the sea.

2.5. Monitoring of seasonal changes

In addition, given that the first-time collection is the result of long-term outflow and drifting, seasonal changes in outflow at the source must also be considered. Therefore, for 197 months from August 1998 to December 2014, we regularly monitored the quantity, source areas, and source regions of drift-ashore lighters once a month on Fukiagehama (1.6 km, Fig. 2; monitoring site) along the west coast of Kyushu.

3. Results

3.1. Drift-ashore density

The median value of drift-ashore density for each coastal area was shown in Fig. 4. The median density on all sites was 6.7 lighters/100 m, and the maximum drift-ashore density (median value) was 72.0 lighters/100 m in Tobishima Island (J_{14}). By sea area, those that had a median density value of more than 10 lighters/100 m were 9 out of 16 coastal areas on the East China Sea coast between Yonaguni Island (E_1) and Tsushima Island (E_{16}) and were 11 out of 13 areas on the Japan Sea coast between Fukuoka (J_1) and Teshio (J_{18}); however, were only four areas out of 18 areas on the Pacific coast between Shibushi Bay (P_1) and Hidaka (P_{14}). The median density on the Izu Islands (Pi) and Ogasawara Islands (Po) in the North Pacific was 7.8 lighters/100 m, and on the Hawaiian Islands (Mw, Ho, Hm, Hk, Hh) in the North Pacific was 5.2 lighters/100 m. However, the density on five sites out of 54 sites in these islands was more than 10 lighters/100 m, and the maximum was 26.0 lighters/100 m. In Alaska (Na_1) of the west coast of North America, the median density was 2.3 lighters/100 m, and on the seven beaches of Oregon, Washington, and British Columbia (Na_2), it was not possible to find lighter despite the beach length of over 100 m. The results show that the density of lighter drift in the North Pacific is extremely high in East Asia, with some hot spots in the central Pacific islands, and low on the west coast of North America.

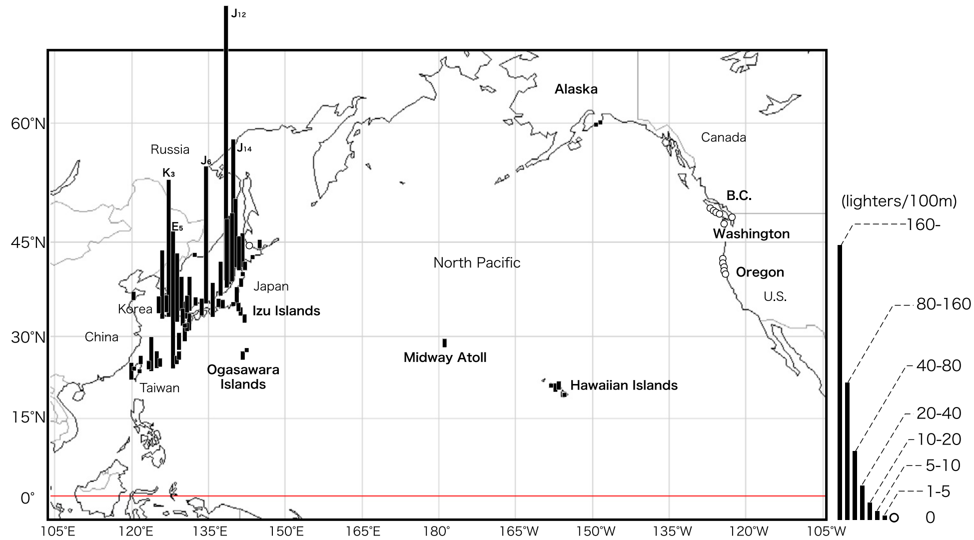

Fig. 4. Median drift-ashore density for each coastal area in the North Pacific.

3.2. Source regions

The percentage of source regions for lighters in the North Pacific are shown in Fig. 5. Of the 79,948 total lighters recovered, 57,444 could be identified as to the source region (six countries), and the total identification rate was 71.9%.

The lighters found in China (C) and Russia (R) were nearly all originated in their own countries. Taiwanese lighters accounted for 76.6% or more of the lighters drifted ashore in Taiwan (T_1 - T_4). Korean lighters accounted for 60.7% or more in South Korea (K_1 - K_4). Japanese lighters are rarely found on the coasts of these countries. On the Japanese coasts of the East China Sea (E_1 - E_{10}), Chinese lighters were 20%–50%, and Taiwanese lighters were more than 20% of the collected lighters. These decreased as we moved northward along the coasts of the Japan Sea. Korea lighters were approximately 10% on the island coasts of the East China Sea (E_1 - E_{11}), and the highest percentage area was more than 40% on the central coast of the Japan Sea (J_3 - J_7). They decreased in quantity in the northern part of the Japan Sea and have flowed out to Pacific Ocean through the Tsugaru Strait. Russian lighters were collected on the coast of the Japan Sea (J_{10} - J_{14}), although the sample size was very small compared with that in other countries. On Pacific coast (P_3 - P_{12}, P_{14}) of Japan, Japanese lighters represented over 80%, and 90% or more on the coast of the inner bay (B_1, B_3 — B_5). On the other hand, they represented with 52.2%–72.7% on Ogasawara Islands (Po) and Midway Atoll (Mw), with 19.2%–49.7% in the Hawaiian Islands (Hm, Hk, Hh, Ho) from all island coasts of the western and central North Pacific. North American lighters were not found on the East Asia coast or on the coasts of Izu Islands (Pi) and Ogasawara Islands (Po) in the western North Pacific, but they accounted for 40% or more of the lighters drifted ashore on the Hawaiian Islands (Hm, Hk, Ho) and the west coast of North America (Na_1, Na_2).

Therefore, using lighters to examine the impact and flow of ML, the lighter flows with the currents, and on the Japanese coasts, it was significantly influenced from neighboring countries, however, when you consider the entire North Pacific, it was showed that the load from East Asia, particularly Japan, is heavy.

3.3. Source areas and flows

Of the 79,948 total lighters recovered, 6484 (8.1%) could be identified as to the source area (city), and the highest was 25.4% in Taiwan. Fig. 6 depicts the distribution of lighter source areas collected in the typical coastal areas around the southern East China Sea, Tsushima/Korea Straits, northern Japan, and Fig. 7 is the North Pacific.

In the East China Sea, the Kuroshio Current flows from Taiwan to southern Kyushu in Japan (Fig. 5), and a strong north wind blows in winter. The source areas of lighters collected on the coasts of Taiwan (T_1 - T_4) were primarily from Taiwan (Fig. 6(a)), where lighters also drifted ashore from the coastal areas of China between Hong Kong and Shanghai but not from Japan. Similar trend was observed in Yonaguni Island (E_1) near Taiwan (Fig. 6(b)). Hence, it was shown that in the East China Sea, the source area of lighters was Nansei Islands in Japan, Taiwan, the coastal area of China between Guangdong Province and Shanghai, and the west coast of South Korea.

On the south coast of South Korea (K_3, K_4), drifting from the southern part of South Korea was the main source of lighters washed ashore (Fig. 6(c)). However, on the south part of the Tsushima/Korea Straits (J_2), drifting ashore from southern South Korea and northern Kyushu was the main course of lighters drifted ashore, including from Taiwan and the coastal areas between Guangdong Province and Shanghai in China (Fig. 6(d)). From this, it was exhibited that the Tsushima/Korea Straits area is affected not only by the outflow from South Korea and northern Kyushu around this strait but also by the coastal areas around the East China Sea.

Fig. 6(e) shows the source areas of lighters collected at Tobishima Island (J_{14}), selected as a representative island from the Japan Sea coast, and Fig. 6(f) is at Ibaraki/Fukushima (P_{10}) from the Pacific coast. On the Japan Sea coast (J_{14}), as in the area around Tsushima/Korea Straits (Fig. 6(c) and (d)), in addition to the outflow of lighters from between Guangdong and Shanghai on the coast of China and from Taiwanese lighters also drifted ashore from the eastern part of South Korea and the southern coastal area of Japan. Ibaraki/Fukushima (P_{10}) shows that the lighter flowed into the Sea of Japan passed through the Tsugaru Strait and moved southward across the Pacific Ocean with the lighter from the northern Tohoku region. The flow of the lighter was consistent with the ocean currents around East Asia shown in Fig. 5.

Most of the lighters collected in the North Pacific Islands such as Ogasawara Islands (Yomejima Island (Po_1), Chichijima Island (Po_2), and Hahajima Island (Po_3)), Midway Atoll (Mw_1), and Hawaiian Islands (Oahu (Ho), Maui (Hm), Kahoolawe (Hk), Hawaii Island (Hh)) originated from the Pacific coast of Japan, such as