Global Fishing Watch

Illuminating Dark Fishing Fleets in North Korea - Analysis for 2019

This document presents a follow-up analysis for the year 2019 of the paper entitled "Illuminating Dark Fishing Fleets in North Korea" published in *Science Advances* on July 22, 2020. By a novel combination of four satellite technologies, Global Fishing Watch (GFW) developed a new methodology to monitor activity of dark fishing fleets – vessels that do not publicly broadcast their location or appear in public monitoring systems – in large areas of sea space. Using the methodology, the study provides detailed information about the previously unmonitored fleets to help fisheries managers collaborate on transboundary fisheries, such as squid, and equip them with cost effective monitoring tools. The sources of data and the methods used for the analysis are the same as described in the published paper. The key findings of the published paper are twofold:

1. Over 900 industrial vessels originating from China in 2017 and over 700 in 2018 were detected fishing intensely in North Korean waters, which is likely in violation of United Nations (UN) sanctions (Resolutions 2371, 2375 and 2397). The detected vessels may also have contravened China's domestic regulations if the fishing was conducted without authorization of the central government of China. This fishing activity resulted in an estimated catch of >160,000 metric tons of Pacific flying squid (*Todarodes Pacificus*) worth US $440 million in 2017-2018.
2. More than 3,000 small-scale North Korean squid vessels were fishing, mostly unauthorized, in Russian waters in 2018. These vessels were in Russian waters because they were likely displaced from their own domestic waters by the presence of the foreign industrial vessels. Many North Korean vessels are washing ashore in Japan as "ghost boats" - battered vessels containing no crew or, in some cases, only human remains.

The following analyses shed light on dark fishing vessels in North Korea in the most recent year, 2019, and provide a comparison with the previous activities of 2017-2018. The key findings of the 2019 analysis presented here are:

1. Foreign fishing activity in North Korea continues at a comparable level to the previous two years with close to 800 vessels originating from China detected in 2019. The estimated catch for 2019 represents US $240 million and the accumulated amount caught, likely in violation of UN sanctions since September 2017, is estimated to be US $560 million in total.
2. The activity of North Korean small-scale fishers in Russian waters returned to levels seen in 2017 while remaining high with over 2,000 vessels detected in 2019. The

number of the reported “ghost boats” in the past five years indicates that it is highly correlated with the number of North Korean small-scale boats found in Russian waters.

1. Daytime optical imagery

An Earth-imaging satellite company, Planet, provided imagery for 2019 in our study area. By using the trained convolutional neural network, a type of machine learning algorithm, described in *Park et al.* (2020), we counted pair trawlers on 14 days in 2019 where coverage and weather were favorable and days are spread over the fishing season (from mid-May to mid-December), with imagery available for an average of 70 percent of our study area (about 90,000 square kilometers) on these dates (see Fig. 1). There were no days meeting favorable conditions for detections in November and December 2019 due mainly to rough seas during the winter. The maximum daily detection was 654 pair trawlers on October 30, 2019.

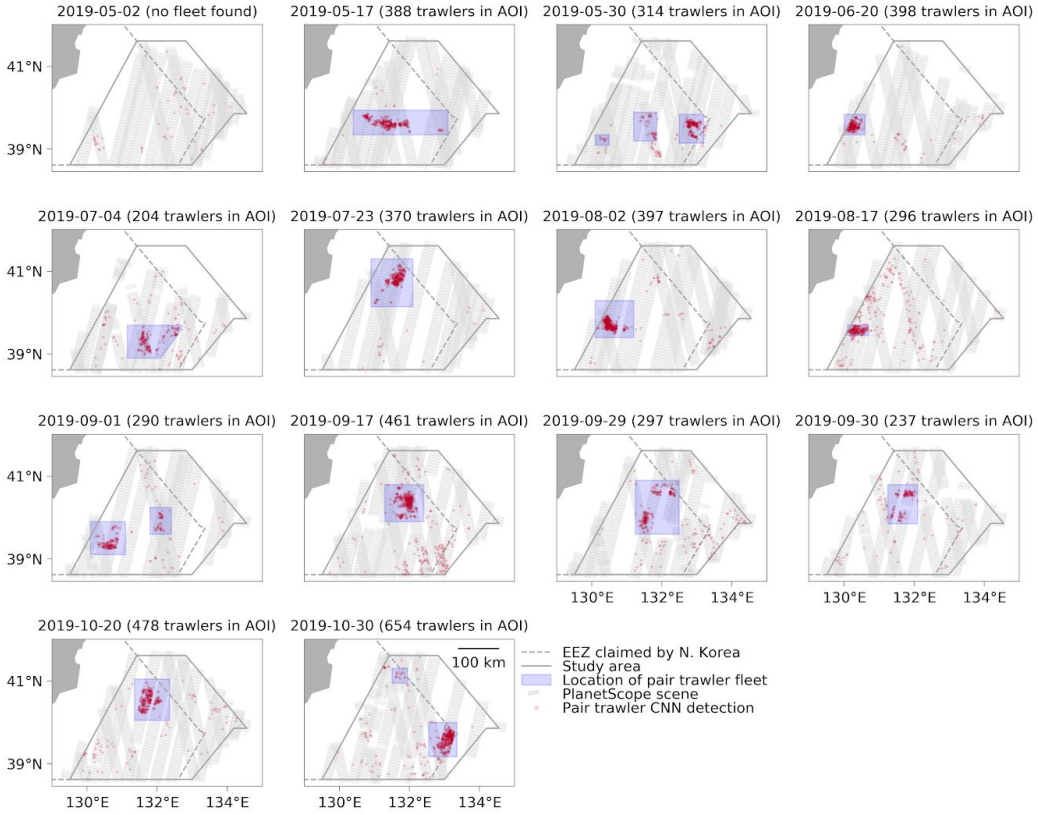

Fig. 1. Pair trawler detections for 2019 by Planet imagery

2. Radar imagery

Synthetic aperture radar (SAR) imagery obtained from European Space Agency was used to detect vessels. To do so, we employed a variation of the Constant False Alarm Rate

algorithm for ship detections (*Park et al.* 2020). The Norwegian satellite company Kongsberg Satellite Services (KSAT) provided Radarsat-2 vessel detections. We counted the number of pair trawlers by counting pairs of detections within the distance of pair trawling, as described in the published paper. The detected pair trawlers in the six SAR images acquired by the Radarsat-2 satellites as well as those in nine of the 21 images from the Sentinel-1 satellites are presented in Fig. 2 and Fig. 3 respectively. Pair trawler vessels were detected by both the daytime optical imagery and the radar imagery on August 2, 2019 (Planet and Sentinel-1) and September 30, 2019 (Planet and Radarsat-2). In both cases, the number of detections by the optical imagery (397 and 327, respectively) was less than the radar imagery (415 and 556) due to smaller areas of interest (in purple boxes in Fig. 1, see *Park et al.* 2020 for the detailed process to define the areas), fewer available scenes from the optical imagery, and the presence of clouds. A more detailed explanation on the differences in vessel counts between different satellite sensor types can be found in *Park et al.* 2020.

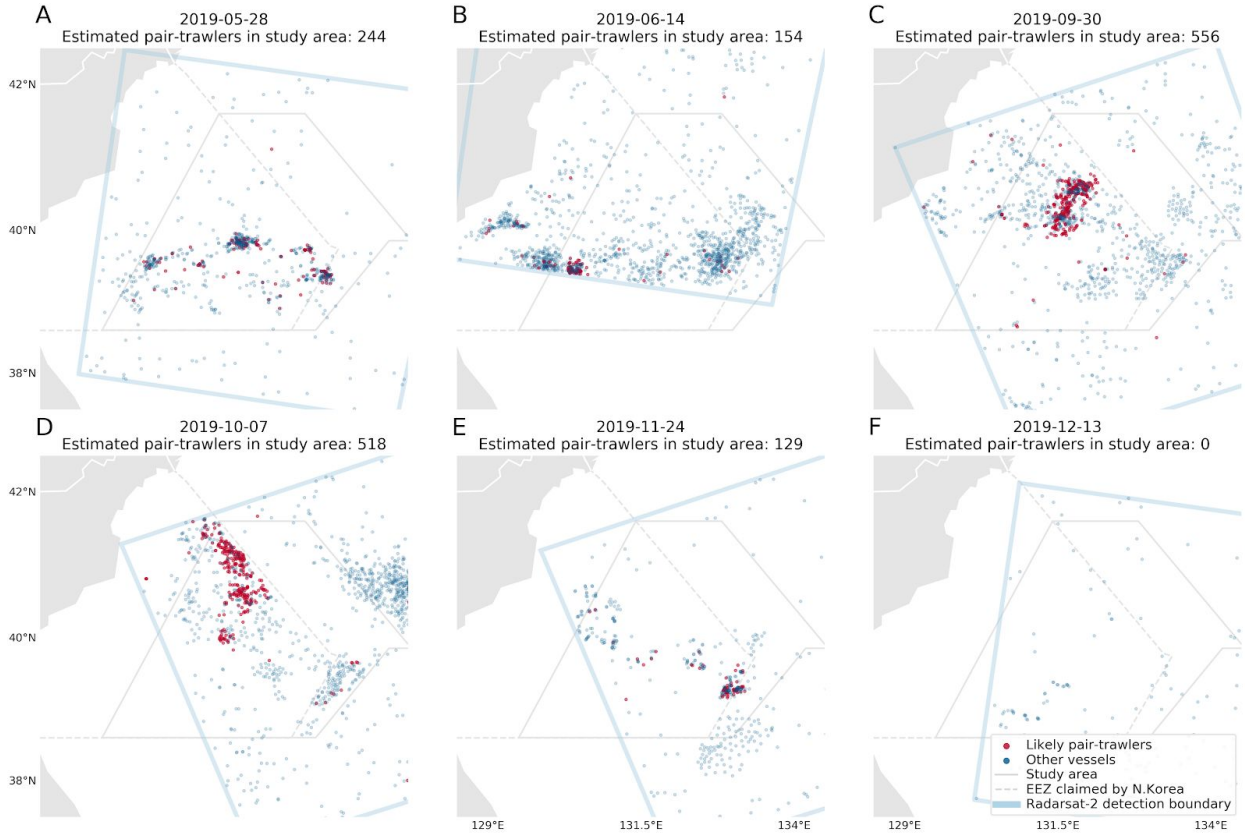

Fig. 2. Pair trawler detections for 2019 by Radarsat-2 images

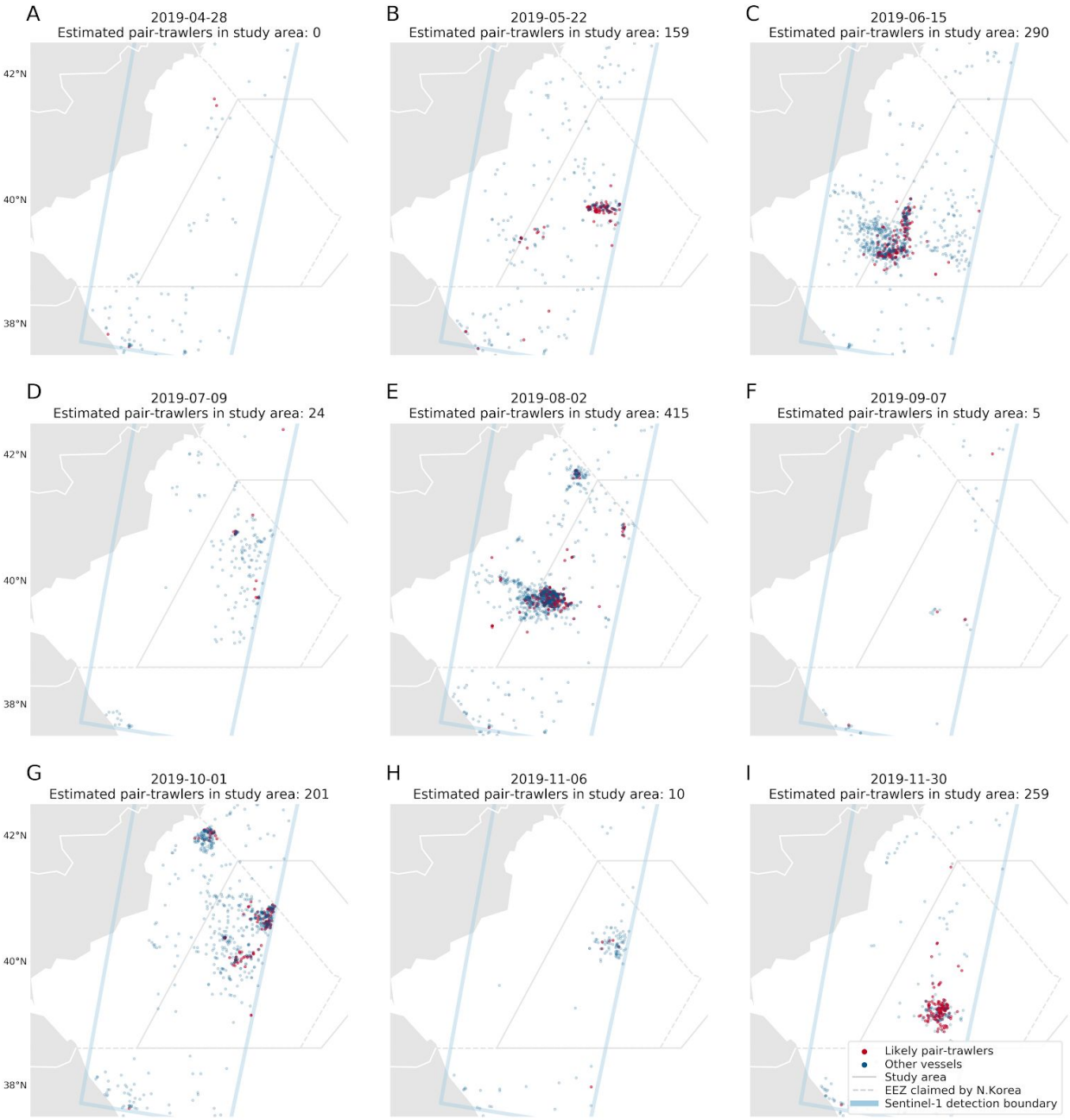

Fig. 3. Pair trawler detections for 2019 on the selected Sentinel-1 images

3. Nighttime optical imagery

Vessel detections on nighttime optical imagery acquired by Visible Infrared Imaging Radiometer Suite (VIIRS) satellite sensors were obtained from the Colorado School of Mines. We differentiated vessels in and around North Korean waters based on brightness, as described in *Park et al.* 2020. Fig. 4 shows three clusters of vessels identified on September 27, 2019: (A) lighting vessels originating from China across the edge of North Korean waters, (B) Japanese or South Korean squid jigging vessels, and (C) North Korean lighting vessels across the edge of Russian waters. In 2019, the maximum daily detection for the lighting vessels originating from

China and North Korea was 136 (with a threshold of >500 nW/cm^2/sr) on September 25, 2019 and 2,030 (<50 nW/cm^2/sr) on September 30, 2019, respectively. The main fishing areas of the different vessels remained practically unchanged compared to the previous years.

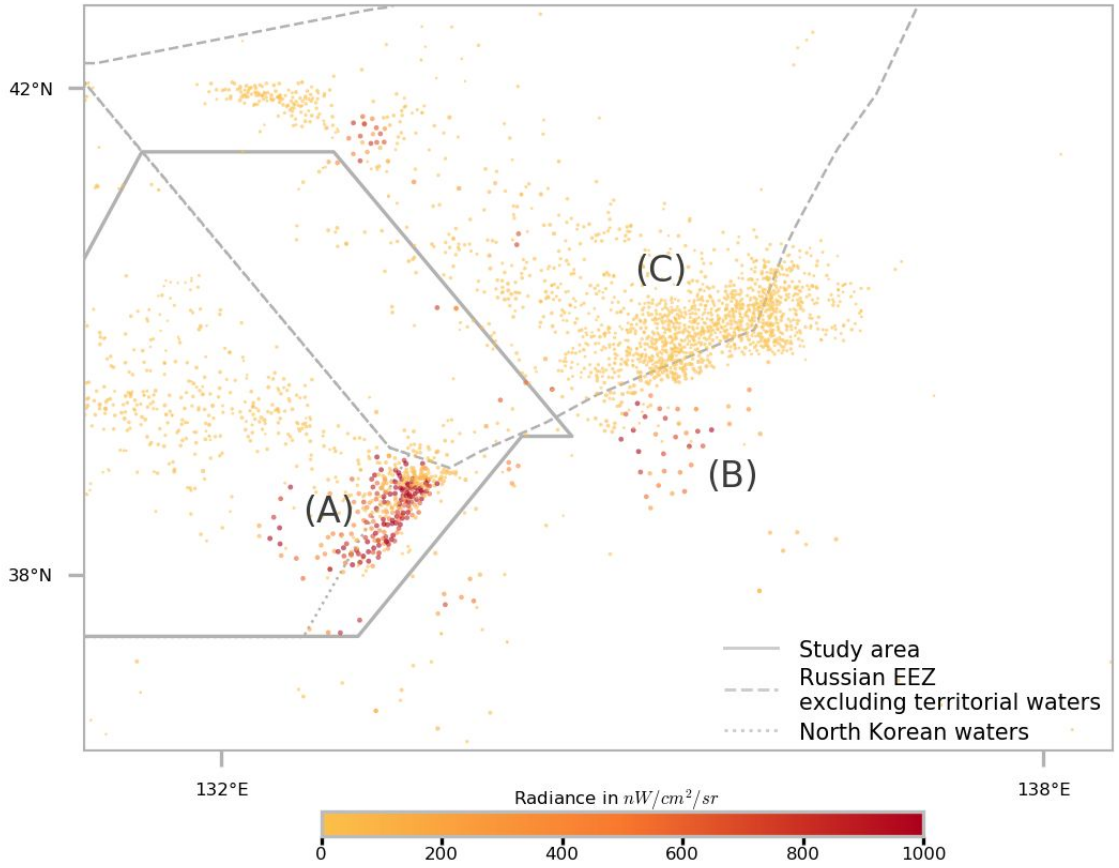

Fig. 4. Lighting vessel detections by VIIRS on September 27, 2019. (A) Lighting vessels originating from China across the edge of North Korean waters, (B) Japanese or S. Korean squid jiggers, and (C) N. Korean lighting vessels across the Russian EEZ.

4. Automatic Identification System

Automatic identification system (AIS) vessel data was obtained by Global Fishing Watch (GFW) from the satellite companies Orbcomm and Spire and processed with methods described in *Park et al.* 2020. Fig. 5. demonstrates likely fishing activity by vessels originating from China fishing in North Korean waters throughout 2019. The fishing activity was derived by GFW's convolutional neural network (see *Kroodsma et al.* 2018). The major areas of fishing, in the southeast corner of the claimed North Korean exclusive economic zone (EEZ), remain similar to the previous two years. The vessels fishing in North Korean waters also fished in China's waters, and appeared to enter and exit ports in China, suggesting that they originate from China. They do not appear to fish in other countries' EEZ nor on the high seas. Their total days of presence in North Korean waters using AIS represents less than 2 percent of the estimated total fishing days in North Korea by these vessels in 2019 (see the next section).

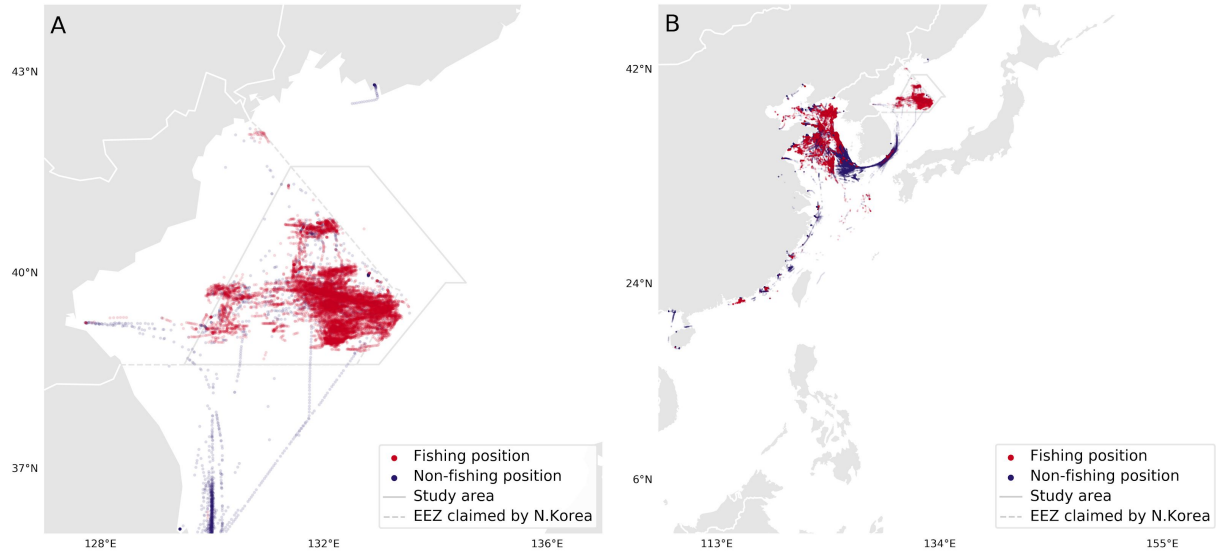

Fig. 5. Origin of the vessels fishing in North Korea and their likely fishing areas. (A) around North Korean waters, (B) East Asian areas including a part of the North Pacific ocean. Note that these vessels fish only in China's waters and North Korean waters in 2019.

5. Estimate of fishing activity and catch in 2019

We used the combination of different satellite detections described above to estimate the total fishing days and catch of the vessels fishing in North Korea. To address gaps in detections due to satellite coverage and weather conditions, we selected days with the most detections for each set of vessels (pair trawlers and lighting vessels) in every half-month period throughout 2019. The South Korea Coast Guard and the East Sea Fisheries Management Service provided data from on-the-water inspections of some of the vessels crossing into North Korean waters, and they counted the number of likely vessels originating from China heading toward North Korean waters each month. We used these on-the-water observations to validate our satellite observations (see Fig. 6). The estimated total fishing days based on the satellite observations for 2019 by both sets of vessels is 82,200 days, representing about 61 percent of the estimate based on the coast guard observations, 134,000 days. Using the most recent data on catch per unit effort for each set of vessels (available for 2018, see *Park et al.* 2020), we estimate a catch of 76,700 metric tons of raw Pacific flying squid, representing an approximate total landing value of US $240 million in 2019.

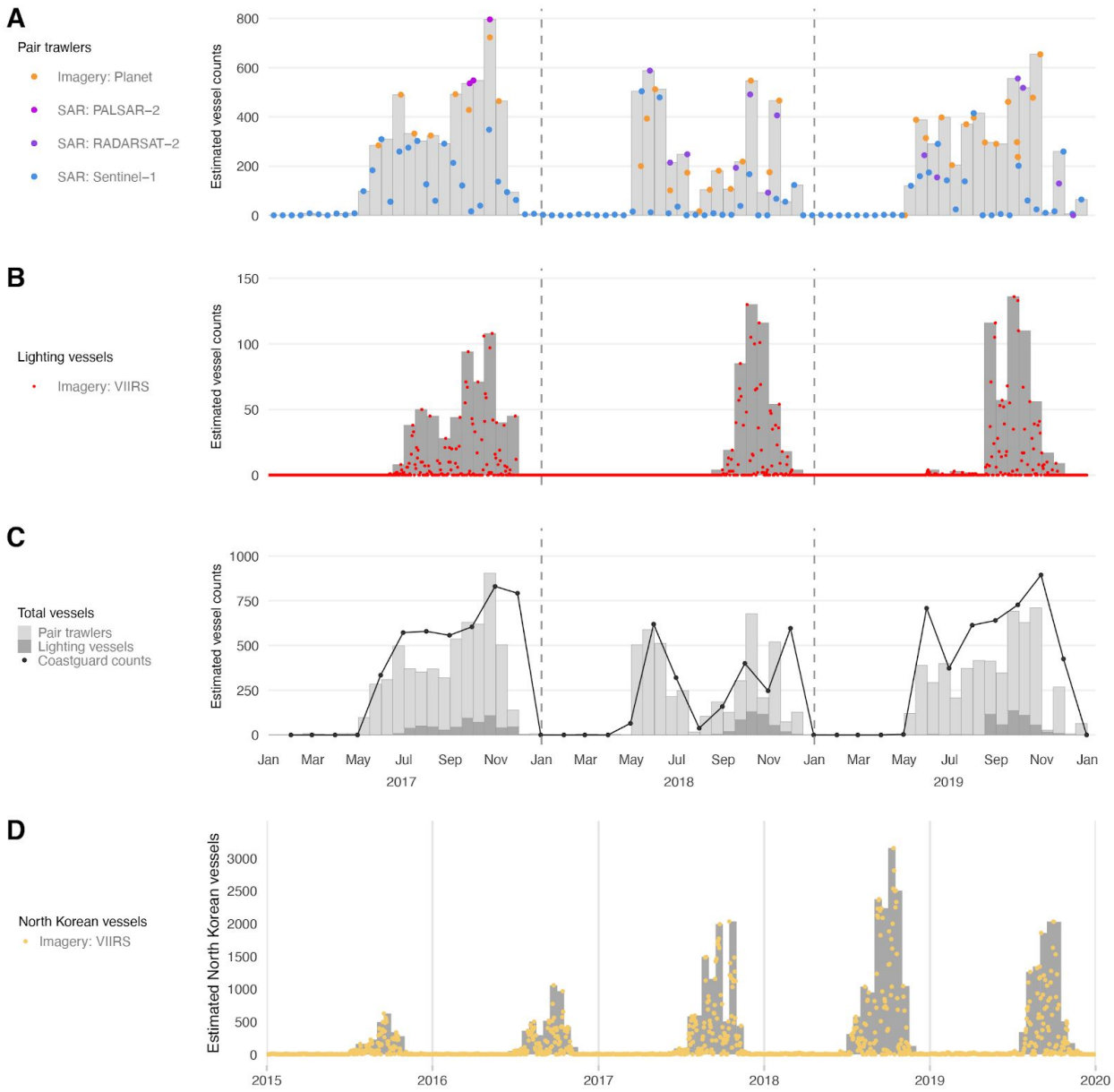

Fig. 6. Satellite tracks of vessels from China and North Korea in 2017-2019. (A) Count of pair trawlers and (B) lighting vessels that originate from China and fish in our study area. Vessel counts are likely underestimates, so we use the maximum count over a half-month period to estimate the number of active vessels. (C) Number of active vessels in the study area (grey bars) is largely consistent with the number of vessels crossing into North Korea observed by the South Korean Coast Guard (black lines). (D) Count of lighting vessels from North Korea operating in Russian EEZ between 2015 and 2019.

Comparison of the fishing activity with previous years

The number of vessels including pair trawlers and lighting vessels originating from China is observed to be 790, a value between those of 2017 (718) and 2018 (904) (Fig. 7A). The estimated total catch based on satellite detections for 2019 (76,700 metric tons) represents about 120 percent and 90 percent of that of 2017 (101,000) and 2018 (63,000) respectively (Fig. 7B), with an almost identical proportion attributed to pair trawlers and lighting vessels each year. However, for 2019, the estimated total fishing days based on the coast guard counts were

slightly higher than both 2017 and 2018 (Fig. 7C). This difference is likely due to gaps in satellite observation during periods of intense fishing, such as the start and end of the fishing season (May through June and November through December). The total squid catch of the vessels represented about 80 percent of the total reported domestic squid catch of South Korea and Japan in all surrounding seas for 2019, which is a notable increase compared to previous years (about 68 percent in 2017 and 2018). This increase indicates that given the potential underestimation of catch in 2019 due to gaps in satellite observation, the catch by the vessels originating from China approaches that of South Korea and Japan combined.

The number of North Korean vessels for 2019 in Russian waters returned to the level of 2017 (Fig. 7D). The estimated total fishing days for 2019 was similar to the days in 2017, but less than those in 2018 (Fig. 7E). The number of North Korean vessels that wash up on the shores of Japan (Fig. 7F), often referred to as ghost vessels, is highly correlated with the number of North Korean vessels in Russian waters and the number of days these vessels fished (Fig 7D and 7E). This trend suggests that the number of so-called ghost boats found on Japanese shores is related to the number of ill-equipped North Korean vessels fishing far into Russian waters.

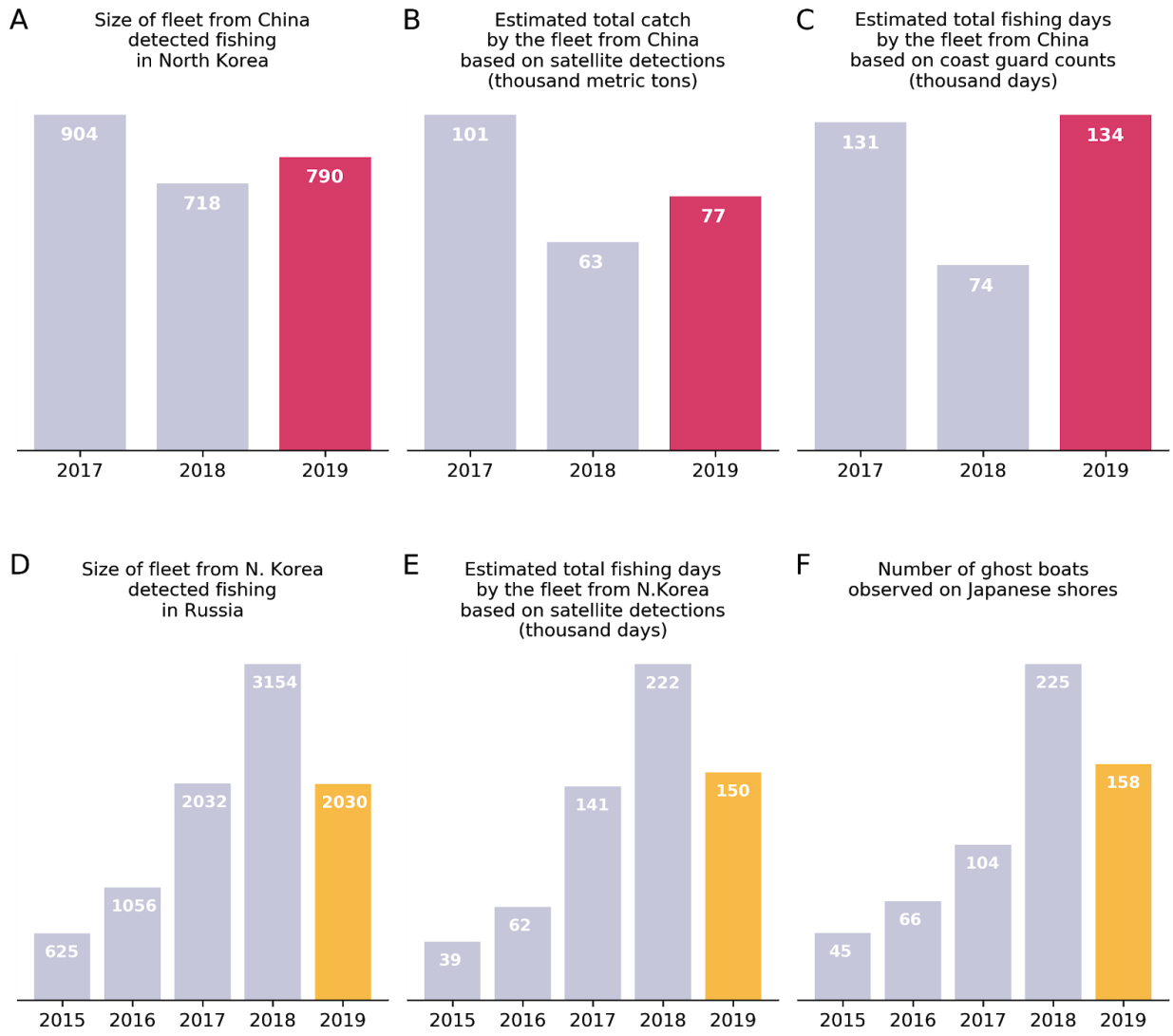

Fig. 7. Yearly comparison of (A) size of detected vessels, (B) their estimated total catch based on satellite detections, and (C) their estimated total catch based on coast guard counts for the vessels from China (2017-2019). For the N. Korean vessels, yearly comparison of (D) size of detected vessels, (E) their estimated total fishing days based on satellite detections, and (F) number of N. Korean ghost boats found on Japanese shore (2015-2019). The height of the bars is scaled to the highest value in each figure.

6. Conclusion

In 2019, foreign fishing activity in North Korea continues at a comparable level (see Fig. 7) to the previous two years reported in *Park et al.* 2020, despite growing scrutiny. The estimated total catch and landing value by these vessels in North Korea based on satellite detections are between the levels of the two previous years, reaching 76,700 metric tons of raw squid, comparable to the total amount reported by fishers from South Korea and Japan. Although the real catch is difficult to compare across years, as satellite coverage varies each year, the estimate based on the coast guard counts suggests that the total fishing days could be higher than those of 2017 and 2018. The estimated catch for 2019 based on satellite detections represents US $240 million and the accumulated amount caught in violation of the UN resolutions since September 2017 is estimated to be US $560 million in total. The activity of North Korean small-scale fishers in Russian waters returned to levels seen in 2017, although there may still be as many as 2,000 maximum daily detections. The comparison of data for the last five years also suggests that the satellite observations of the number of North Korean vessels fishing in Russian waters highly correlates to the recorded number of ghost boats washed ashore in Japan.