Illuminating dark fishing fleets in North Korea

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Illuminating dark fishing fleets in North Korea

Abstract
2020 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC). Illegal, unreported, and unregulated fishing threatens resource sustainability and equity. A major challenge with such activity is that most fishing vessels do not broadcast their positions and are "dark" in public monitoring systems. Combining four satellite technologies, we identify widespread illegal fishing by dark fleets in the waters between the Koreas, Japan, and Russia. We find >900 vessels of Chinese origin in 2017 and >700 in 2018 fished illegally in North Korean waters, catching an estimated amount of Todarodes pacificus approximating that of Japan and South Korea combined (>164,000 metric tons worth >$440 million). We further find ~3000 small-scale North Korean vessels fished, mostly illegally, in Russian waters. These results can inform independent oversight of transboundary fisheries and foreshadow a new era in satellite monitoring of fisheries.

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Illegal, unreported, and unregulated fishing threatens resource sustainability and equity. A major challenge with such activity is that most fishing vessels do not broadcast their positions and are “dark” in public monitoring systems. Combining four satellite technologies, we identify widespread illegal fishing by dark fleets in the waters between the Koreas, Japan, and Russia. We find >900 vessels of Chinese origin in 2017 and >700 in 2018 fished illegally in North Korean waters, catching an estimated amount of Todarodes pacificus approximating that of Japan and South Korea combined (>164,000 metric tons worth >$440 million). We further find ~3000 small-scale North Korean vessels fished, mostly illegally, in Russian waters. These results can inform independent oversight of transboundary fisheries and foreshadow a new era in satellite monitoring of fisheries.

INTRODUCTION
In October 2018, world leaders pledged more than $10 billion to protect the world’s oceans (1). A major objective of this initiative is to reduce illegal, unreported, and unregulated (IUU) fishing, which results in the loss of billions of dollars, threatens fish stocks and marine ecosystems, and jeopardizes the livelihoods and food security of legitimate fishers and communities (2). IUU fishing, however, is often conducted by “dark fleets”—vessels that do not appear in public monitoring systems (3, 4)—and is therefore difficult to monitor and enforce (5). Although many dark vessels operate legally and broadcast their positions on country-mandated vessel monitoring systems, these data are often tightly guarded, limiting usability for third-party oversight or transboundary management. Revealing the activities of dark vessels could address this information gap, improving transparency and accountability.

These challenges with dark fleets and IUU fishing are epitomized in the waters between North Korea, South Korea, Japan, and Russia, where geopolitical tensions and disputed boundaries create a vacuum of shared data and management (6). In these poorly observed waters, the same stocks of Todarodes pacificus (Japanese flying squid) are targeted by several fleets, including the Chinese distant-water fleet (7, 8). Although the Chinese fleet has fished in North Korean waters since 2004, its fishing activity and catches are only intermittently published, and not since 2016 (table S6). This lack of information sharing prevents accurate stock assessment in a fishery where restricted access and enforce (9, 10). This inability to assess the stock is concerning considering the critical importance of squid in the region. T. pacificus is South Korea’s top seafood by production value (9), one of the top 5 seafoods consumed in Japan (11), and, until recent sanctions, was the third largest North Korean export (12).
satellite constellation, PlanetScope, covering most of the claimed North Korean EEZ in 2017 and 2018 (see fig. S1 for a map of our study area). We then trained a convolutional neural network to identify pair trawlers in this imagery, as these vessels show a distinctive fishing pattern and comprise the largest proportion of foreign vessels in the region (Fig. 1, A, B, and D, and figs. S2 to S4 and S25). After identifying the location of the fleet with the neural network, we tasked Planet’s 0.72-m resolution SkySat satellites to image these vessels, further verifying that they are pair trawlers (Fig. 1C). We also used SAR imagery from three different satellites to verify the location and size of the fleet (Fig. 1E, figs. S7 to S11, and tables S2 and S3). With these data, we estimate that at least 796 distinct pair trawlers operated in North Korean waters in 2017 and at least 588 did so in 2018. Only a fraction of these vessels broadcast AIS (fig. S15); but the signals from these AIS-broadcasting vessels demonstrate that the vessels originated from Chinese ports and fished in Chinese waters (Fig. 2 and figs. S12 to S17). To further verify their Chinese origin, we matched AIS detections from 140 of these vessels to Planet imagery (Fig. 1, B and D, and fig. S5). The AIS signals of these vessels corroborate the South Korean Coast Guard’s inspections, confirming that they originated from China.

The second most common fishing vessels thought to be of Chinese origin in North Korean waters are large, 55- to 60-m “lighting vessels” that use bright lights to lure target species (Fig. 3A, fig. S26, and movie S3); we identify these vessels by using low-resolution, high-sensitivity optical imagery (VIIRS) acquired at night. Although several fleets in the region use lights, Chinese vessels are known to be by far the brightest, carrying up to 700 incandescent bulbs and generating over 1000 lux, equivalent to the light of some football stadiums (13). This brightness allows us to distinguish these vessels from other fleets in the area (figs. S18 to S24), and we confirmed this vessel classification by tasking Planet’s higher-resolution SkySat to image an area where these bright vessels clustered (Fig. 3B). VIIRS enables us to estimate a minimum of 108 lighting vessels of Chinese origin operating in North Korean waters in 2017 and 130 in 2018. We also detected low-intensity lighting vessels, identified as the North Korean small-scale fleet. This fleet consists of small 10- to 20-m wooden vessels with only 5 to 20 bulbs (Fig. 3C and fig. S27). We further verified vessel type through SAR (Fig. 3D) and Planet imagery of the port of Chongjin, North Korea (fig. S6). We estimate that about 3000 North Korean vessels fished in the Russian EEZ during 2018 (Fig. 4D).

Data from these satellites also allow us to quantify changes in vessel activity over time. For the North Korean small-scale vessels, we estimate that the number of fishing days has increased every year in the past 4 years from 39,000 in 2015 to 222,000 in 2018 (Fig. 4D). For vessels originating from China, we estimate 91,400 fishing days during 2017 (82,600 by pair trawlers and 8800 by lighting vessels) and 67,300 fishing days during 2018 (60,700 by pair trawlers and 6600 by lighting vessels) (Fig. 4, A to C). These figures account for 70% in 2017 and 91% in 2018 of the number of fishing days one would estimate based on the number of Chinese vessels crossing into or out of North Korean waters each month, as counted by the South Korean Coast Guard (Fig. 4C and tables S4 and S5). If we conservatively assume that the catch per unit effort (CPUE) for pair trawlers and lighting vessels of Chinese origin is similar to that of

![Fig. 1. Activity of pair trawlers originating from China in North Korean waters.](image)
smaller vessels in nearby waters, the total estimated likely Chinese catch would correspond to approximately 101,300 metric tons of squid worth $275 million in 2017 and 62,800 metric tons of squid worth $171 million in 2018 (13). Such catch figures would approximate those of Japan and South Korea combined from all their surrounding seas (13).

**DISCUSSION**

This large number of previously unmonitored vessels poses a substantial challenge for stock management. A political stalemate due mainly to sovereignty conflicts and maritime boundary disputes has prevented regional joint fisheries management (20), while existing state-based efforts are ineffective because of a lack of shared vessel monitoring data, management arrangements, and comprehensive stock assessments. For instance, to prevent overfishing, South Korea sets the total allowable catch for squid, limits the lighting power of squid jiggers, bans pair trawling, and permits fewer than 40 small trawlers (13, 21–23). The likely Chinese fleet, however, targeting the same stock, uses brighter lighting power, pair trawling, and a greater number of vessels (13). Given the declining CPUEs of South Korean and Japanese squid jiggers and the drastic decline in squid larval densities since 2003 (24, 25), the large number of vessels revealed through this study is particularly concerning.

In addition to sustainability concerns, there are also substantial implications for fisheries governance and regional geopolitics. These vessels originate from China and, based on inspections by the South Korean authorities, are assumed to be owned and operated by Chinese interests (13). However, because the vessels often do not carry appropriate papers, they may plausibly be so-called “three-no boats” operating outside of official Chinese authority, with no registration, no flag, and no license to operate (26). If these vessels do not have approval from both the Chinese and North Korean governments, they are fishing illegally; Chinese regulations require ministerial approval to fish in foreign waters (15), and the UN Convention on the Law of the Sea grants coastal states sovereign rights to manage living marine
resources in their waters (27). Alternatively, if they are operating with approval from either or both governments, those state(s) are in violation of UN Security Council sanctions. Notably, the Chinese government has repeatedly refuted this latter scenario, confirming its support for the current sanctions (13). Regardless of the scenario, each results in the violation of either or both international and domestic law. Bearing this in mind, our analysis identified over 900 distinct illegal vessels in 2017 after sanctions began and over 700 in 2018, representing the largest known case of illegal fishing perpetrated by a single distant-water fleet (2, 28, 29).

The presence of this foreign fleet also has severe consequences for North Korean small-scale fishers. Evidence suggests that competition...
from these larger trawlers displaces these small-scale wooden boats, shifting substantial effort to neighboring Russian waters. This kind of shift in response to foreign fleets has been documented elsewhere (30) and is also consistent with local fisheries ecology in this region. During the last trimester of the year, Japanese flying squid migrate south, through the Russian EEZ (7), providing an opportunity for the North Koreans to fish before the foreign fleets deplete the stock. A large portion of this North Korean fishing in Russian waters is, however, also illegal. The Russian government has authorized fewer than 100 North Korean boats since 2014, and in 2017, no permits were granted (13). In contrast, we estimate about 3000 vessels fished in these waters during 2018. North Korean artisanal boats are severely underequipped for the long-distance travel required to reach Russian fishing grounds (movies S1 and S2). As a result, between 2014 and 2018, 505 North Korean boats washed ashore on Japanese coasts. These incidents frequently involve starvation and deaths, and local media reports that many fishing villages on the eastern coast of North Korea have now been coined “widows’ villages” (13). The illegal fishing patterns documented here likely exert a heavy toll on fish and fishers alike.

We suggest that this analysis represents the beginning of a new era in satellite monitoring of fisheries. Multiple satellite sources have long been available to government agencies for targeted surveillance. However, it is only with recent increases in data availability, accessibility, and computing power that these techniques can now be performed at large enough spatial and temporal scales—and by small, independent groups of researchers—to enable transparent fisheries monitoring. Although some aspects of this study are particular to the region (e.g., prevalence of pair trawlers), most techniques are easily transferable, such as matching AIS to vessel detections from freely available global satellite imagery or radar. And for the satellite data sources that are not yet freely available, such as commercial satellite radar or high-resolution optical imagery, the cost per image is decreasing rapidly (13). Combining these satellite technologies can reveal the activities of large fleets, filling a major gap in the management of transboundary fisheries. Furthermore, these technologies, when accompanied by local expertise, can identify potential hot spots of illegal, unregulated, or unreported fishing. Global fisheries have long been dominated by a culture of confidentiality and concealment, and achieving a comprehensive view of fishing activities at sea is an important step toward sustainable and cooperative fisheries management.

MATERIALS AND METHODS

The analysis on fishing access agreements in the region is presented in section S1. All satellite data sources and methods to identify fishing vessels operating in and around North Korean waters are explained in detail in sections S2 to S5 (optical imagery in section S2, SAR in section S3, AIS in section S4, and VIIRS in section S5). We describe in section S6 the information obtained from South Korean authorities and various observations on the waters to validate our estimate of vessel presence and fishing activity. The legal analysis of the detected fishing activity is provided in section S7. Section S8 demonstrates the method for estimating the amount and the monetary value of the total catch in 2017–2018.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/6/30/eabb1197/DC1

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