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Reliable estimation of IUU fishing catch amounts in the northwestern Pacific adjacent to the Japanese EEZ: Potential for usage of satellite remote sensing images

Yoshioki Oozeki[a,*], Denzou Inagake[b], Tsutomu Saito[b], Makoto Okazaki[c], Ippei Fusejima[d], Makoto Hotai[e], Tomowo Watanabe[a], Hiroya Sugisaki[b], Masanori Miyahara[a]

[a] Headquarters, Japan Fisheries Research and Education Agency, 2-3-3 Minato-mirai, Nishi, Yokohama, Kanagawa 220-6115, Japan
[b] National Research Institute of Fisheries Science, Japan Fisheries Research and Education Agency, 2-12-4 Fukuura, Kanazawa, Yokohama, Kanagawa 236-8648, Japan
[c] Yokohama Laboratory, National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency, 2-12-4 Fukuura, Kanazawa, Yokohama, Kanagawa 236-8648, Japan
[d] Marine Fisheries Research and Development Center, Japan Fisheries Research and Education Agency, 2-3-3 Minato-mirai, Nishi, Yokohama, Kanagawa 220-6115, Japan
[e] Japan Purse Seiners' Association, 3-11-3 Nagahama, Chuo-ku, Fukuoka 810-0072, Japan

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ABSTRACT

To establish an estimation procedure for reliable catch amount of illegal, unreported and unregulated (IUU) fishing, light-gathering fishing operations in the northwestern Pacific were analyzed based on the Visible Infrared Imaging Radiometer Suite (VIIRS) day/night band (DNB) data provided by the Suomi National Polar Partnership (SNPP) satellite. The estimated fishing activities were compared with the navigation tracks of vessels obtained from the automatic identification system (AIS). As a model case, the fishing activities of Chinese fishing boats using fish aggregation lights outside the Japanese EEZ in the northwestern Pacific were analyzed from mid-June to early-September 2016. Integration analyses of VIIRS DNB data and AIS information provided reliable data for estimating the fishing activities of Chinese fishing boats and suggested the importance of estimating fish carrier ship movements. The total amount of the chub mackerel (*Scomber japonicus*) catch during this period was independently estimated from three angles: 1) the fishing capacity of the fishing boats, 2) the freezing capacity of refrigeration factory ships and 3) the fish hold capacity of the fish carrier ships, based on information obtained from interviews with Chinese fisheries companies. These estimates indicated that the total amount of mackerel catch by Chinese fisheries was more than 80% of the allowable biological catch (ABC) of Japan in this area in 2016. This suggests that Pacific high seas fishing has a significant impact on the future of fish abundance. Our proposed procedure raises the possibility of evaluating the fishing impact of some forms of IUU fisheries independently from conventional statistical reports.

1. Introduction

The threat of illegal, unreported and unregulated (IUU) fishing to marine living resources is receiving a great deal of attention in many international fora, such as the United Nations' Sustainable Development Goals [33] and various studies [1,29]. IUU fishing is not a new issue: it has been observed both within EEZs and on the high seas for at least the past three decades. Even though great efforts have been expended at the national, bilateral, multilateral and global levels to halt IUU fishing, the threat continues to grow [27]. This could result in unreliable assessments of fish stocks and ineffective fisheries management if IUU fisheries continue [11]. The FAO and intergovernmental organizations have repeatedly issued warnings against IUU fisheries since the early 1990s [9,34]. It has been emphasized that IUU fishing can damage vulnerable fish stocks and/or fish stocks still recovering from serious overexploitation [2]. In response, the FAO developed the "International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU)" [10]. Then the FAO promoted the establishment of the Port State Measures international agreement as an effective tool for eliminating IUU fisheries [12,30]. However, these actions have yet to produce the intended outcome, *i.e.*, of containing IUU fishing. Instead the catch amount of IUU fisheries seems to be increasing, and IUU fisheries appear to be expanding to other areas in different forms [27].

* Corresponding author.
E-mail address: oozeki@affrc.go.jp (Y. Oozeki).

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The expansion of IUU fisheries has been observed in the high seas areas of the northwestern Pacific recently. Chinese Taipei fishing vessels increased their catch of Pacific saury, *Cololabis saira*, from 27,900 metric tonnes (MT) (2000) to 165,700 MT (2010) in the 2000s in this region, while almost no substantial fishing activities had previously been conducted [32]. Following this expansion of Chinese Taipei's fishing, the People's Republic of China (here referred to as 'China', and excluding Taiwan, Hong Kong and Macau) joined the fishing there in 2012. However, the Chinese fishing fleets did not remain solely in saury fishing, but expanded to other pelagic fisheries. In the last few years, Chinese tiger-net and stick-held dip net fishing boats have been increasingly sighted on the high seas in this region. In 2016, Japanese Fisheries Agency (JFA) patrol vessels recorded more than 200 Chinese boats [15]. The types of fishing gear using fish aggregation lights are like purse seines but are much more efficient in catching all kinds of fish, such as sardine, mackerel, squid, saury, and juveniles of many species in the pelagic water of the fishing grounds. According to the North Pacific Fisheries Commission (NPFC), a newly established RFMO responsible for fisheries in this region, the Chinese catch of chub mackerel, *Scomber japonicus*, which is the most expensive and thus assumed to be the main target species, increased markedly from 24,629 MT by 20 fishing boats in 2014 to 142,994 MT by 89 fishing boats in 2016 [16]. However, false identification of vessels is frequently recorded in photos taken by Japanese patrol vessels. These cases include (1) multiple Chinese boats displaying the same name and registration number, and (2) boats displaying a different vessel name on each side of their hull [15]. As a result, the number of fishing boats and the amount of catch are likely to be considerably under-reported.

The NPFC established the "Conservation and management measure on information requirements for vessel registration" on 3 September 2015 [22]. The agreement adopted at the same meeting indicated that unlisted fishing vessels operating in this region should be recognized as IUU fishing boats [23]. Catch amount should be reported to the NPFC until the end of February and fishing fleets that did not record or report their catch are recognized as IUU fishing [23]. According to the observation at sea by the Japanese patrol and research vessels, it is unquestionable that a significant number of false identification vessels, *i.e.*, IUU vessels, are operating in this region in addition to the duly licensed Chinese fishing boats. NPFC adopted resolutions in 2015 and 2016 calling for self-restrictions of each member upon further increase of fishing vessels fishing for Pacific saury and chub mackerel [21,24]. While the Chinese government appears to have made efforts to contain the increase in fishing vessels, it seems that a significant number of unlicensed Chinese fishing vessels have started fishing in this region. Thus, the reported catch data cannot be solely relied upon, and it is crucial to find a way to assess actual fishing effort and catch, including IUU fishing, in the relevant stock assessments. Otherwise, fishing impacts upon the stocks would be underestimated and the assessment would result in an unreasonably optimistic future of the stocks. Fortunately, the recent introduction of new satellite technologies and other useful information-monitoring systems has enhanced our abilities to assess IUU activities and their impact on marine resources even in high seas area.

The Suomi National Polar Partnership (SNPP) satellite, carrying sensors for illuminated intensity, was launched in 2011 for global observation of the Earth. It enabled us to obtain more reliable and precise information on the activities of fishing boats that use fish aggregation lights. The real-time observation of brightly-lit fishing boats was reported as early as the 1970s [5,6]. This satellite is equipped with the Visible Infrared Imaging Radiometer Suite (VIIRS) as its primary image sensor. The VIIRS day/night band (DNB) collects even low light image data with high horizontal spatial resolution of down to approx. 0.75 km × 0.75 km [7,18,19]. Increased data volume with high resolution and the lower detection limit in radiance has created a new operational field to monitor the activities of dimly-lit fishing boats and process algorithms for eliminating several types of noise [8].

Another information source has become available recently. Automatic identification systems (AIS) were made a requirement for international cruising vessels with a gross tonnage of 300 t or more by the International Convention for the Safety of Life at Sea (SOLAS) in 2002. AIS started as a coastal communication tool. Later, a satellite AIS network was established after the STS-129 space shuttle mission in 2009, during which shipboard AIS signals using the VHF band were observed to reach up to 400 km vertically, although the AIS has a horizontal range limit of only 40 nautical miles (74 km). ORBCOMM currently operates the AIS network service (http://www.orbcomm.com/en/industries/maritime/satellite-ais, downloaded on Sept. 23rd, 2016) and information service companies provide analysis of AIS information *via* the internet (Shipfinder: http://shipfinder.co/, Marinetraffic; http://www.marinetraffic.com/, downloaded on Sept. 23rd, 2016). These information systems are useful data sources for current scientific analyses [28]. However, several problems related to the operation of AIS have been reported, *e.g.*, deliberate suspension of signal transmissions from the onboard AIS, low reliability of AIS signals, including incorrect datum setting and the security vulnerability of AIS itself [13]. In spite of these particular drawbacks, AIS is still a powerful tool for monitoring the activities of target vessels because of the huge amount of AIS data being accumulated on a close to real-time basis.

The Chinese fishing boats in the northwestern Pacific operate at night and use fish aggregation lights. Thus, the above two new information sources can be used to analyze their movements. VIIRS DNB data provide the information on fishing operations at night, while AIS simultaneously reports the ship's name, size, location, speed and heading. In the present study, seasonal changes in patterns of fish aggregation lights were first described on the high seas area of the northwestern Pacific from May 2013 to September 2016. Then, the nightly distribution of fishing boats analyzed using the VIIRS DNB data was compared with the navigation records reported from the AIS, with the support of observation reports from Japanese fishery patrol vessels, during a period from the middle of June to early September 2016. To estimate the total amount of catch, several Chinese refrigeration factory ships and fish carrier ships were tracked using AIS information as examples. Information on fishing activities was also obtained during interviews with fisheries companies and vessel-building industries in China. Catch amounts made in the target area were estimated based on these data, the information on the fishing capacity of fishing boats from the NPFC vessel data, [25] and by holding interviews. Our proposed procedure opens the potential for evaluating the fishing impact of IUU fisheries independently from the conventional reported catch data.

2. Materials and methods

2.1. VIIRS DNB information

Real-time data from the Suomi National Polar-orbiting Partnership (SNPP), operated by NOAA, were downloaded from Wisconsin State University's ftp site, in addition to the archived data since 2013 (ftp://snpp.ssec.wisc.edu/ingest/viirs/npp/, downloaded daily). Visible Infrared Imaging Radiometer Suite (VIIRS) Day-Night Band (DNB) data and cloud masking (CM) data were included in the daily obtained data set (Fig. 1). Pixels indicating local maximum values of radiance were first extracted by comparison with the surrounding radiance values from the dataset of DNB (Figs. 1, 2A).

Various error sources in the DNB data, including the reflections of sun, moon and starlight reflected by clouds and other types of noise, were eliminated step-by-step (Fig. 1). The effect of sunlight was first eliminated according to the value of SZA during two months around the summer solstice north of 40°N. Then, the possible lights from fishing boats were selected, taking into account the effects of cloud and the moon (Fig. 1, Fig. 2B). At the same time, the halo noise around the light points of fishing boats, which was observed when the light passed