

Case Study 10

Use of Night Satellite Imagery to Monitor the Squid Fishery in Peru

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10.1 Introduction

The giant squid (*Dosidicus gigas*) lives mainly in the oceanic environment, but also occurs in neritic (relatively shallow) environments, and makes horizontal and vertical migrations. It is a physiologically tolerant species, characterized by opportunistic consumption habits and is also considered an ecologically important species, acting as predator and prey of a large number of species (including their own species). The distribution of *Dosidicus gigas* is far reaching since it is a highly migratory species. In the eastern Pacific Ocean its geographic habitat is from California (37°N) to southern Chile (47°S) and from the coasts of North and South America to 125°W. The greatest concentrations are located in the Peruvian coastal oceanic region in the southern hemisphere, and the Gulf of California in the northern hemisphere (Nesis, 1983). In Peru, the fishing activity of the giant squid or "pota" is exerted mainly by industrial Japanese and Korean squid jigging vessels with a holding capacity of 300–1000 tonnes, which have been fishing off Peru since 1991 (Taïpe, 2001).

The squid jigging vessels operate at night, using powerful lights (2000 watts) to attract the squid. The lights are set at a specific height and angle to allow for a shade zone next to the ship where the squid concentrate. The number of lights per ship varies between 120 and 200 depending on vessel capacity. Squid are attracted to the light, creating massive concentrations around the luminous source, and allowing for easy harvest.

These lights can be observed as bright-light areas on night-time OLS (Operational Linescan System) images of the Defense Meteorological Satellite Program (DMSP). Cho et al. (1999), Kiyofuji et al. (2001), Rodhouse et al. (2001) and Waluda et al. (2002) have examined night-time visible images to determine the spatial distribution of fishing vessels. Cho et al. (1999) and Kiyofuji et al. (2001) determined that the bright areas in the OLS images, created by 2-level slicing, were caused by light

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produced by the fishing vessels. Rodhouse et al. (2001) reported the frequency of light occurrences in cloud-free imagery, and associated these lights with fishing vessels. Waluda et al. (2002) analyzed the relationship between the number of lit pixels in DMSP/OLS night-time visible images and the number of fishing vessels around the Falkland Islands' fishery for *Illex argentinus*. Kiyofuji et al. (2004) examined the relationship between the number of pixels in the DMSP/OLS imagery and the number of fishing vessels, and demonstrated that fishing vessel numbers can, in fact, be estimated from DMSP/OLS night-time visible images. Kiyofuji and Saitoh (2004) used night-time visible images to detect Japanese common squid fishing areas and potential migration routes in the Sea of Japan.

The industrial fishing of giant squid (*Dosidicus gigas*) has been monitored through the ARGOS satellite tracking system since 1998, and is directed primarily at licensed vessels that fish off the Peruvian coast. However, other vessels are known to be engaged in fishing operations within the Peruvian Exclusive Economic Zone (EEZ), which cannot be detected by the system. For this reason, IMARPE has been using an alternate system of night satellite imagery since July 2003, that permits observation of the areas where squid vessels are operating.

The increasing demand for fishing resources and the necessity to exploit these from an economical view point, have encouraged fishing countries such as Peru to implement technologically advanced satellite systems for surveillance and control of fishing vessels, to better manage the fishing resources. This case study describes an example of how we use night-time satellite imagery to detection the location of squid fleets inside and outside the EEZ with the objective of understanding the distribution, concentration and characteristics of squid fishing fleets.

10.2 Study Area

The study area is located off the coast of Peru, between 3–18°S and 70–85°W. This area is dominated by the Humboldt-Peru eastern boundary current system, which generates the cold nutrient-rich coastal upwelling that makes this region so productive.

10.3 Materials and Methods

10.3.1 DMSP-OLS imagery

DMSP/OLS data were provided by the NOAA National Geophysical Data Center (NGDC) in Boulder, Colorado, USA. The DMSP satellite carries six sensors including the OLS. The OLS sensor monitors global cloud coverage by day and night via two channels (visible-near-infrared (VNIR) and thermal-infrared (TIR)), and has a swath of 3000 km. The VNIR and TIR channels observe radiation from 0.5 to 0.9 μm , and

from 10 to 13 μm , respectively. The VNIR band signal is intensified at night using a photomultiplier tube (PMT) for the detection of moonlit clouds. The low-light sensing capability of OLS at night permits the measurement of radiance down to $10^{-9} \text{ W cm}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}$ (Elvidge et al. 1997a). However, the OLS is sensitive to scattered sun light, which saturates the visible band data (referred to as "glare" in the literature, Elvidge et al. 1997b). The visible band of DMSP/OLS has a 6-bit quantization, producing digital numbers (DN) ranging from 0 to 63 (Elvidge et al. 1999). Visible band digital numbers are relative rather than absolute values, with units in W m^{-2} .

DMSP Visible and IR images can be downloaded free of charge (June 1992 to present) from <http://spidr.ngdc.noaa.gov/spidr>. The web site provides data from 9 DMSP satellites, both day and night. The format of these images is L0 level (.OIS files) which therefore require digital processing in ENVI, ERDAS or other software. For this case study we used the image of 2 October 2008 (20:49 local time) obtained from DMSP for the coverage area $0\text{--}20^{\circ}\text{S}$ and $70\text{--}90^{\circ}\text{W}$, corresponding to the area where the squid fishery was operational. OLS information is pre-processed by the National Geophysical Data Center (NGDC) and obtained through an annual subscription, which includes the use of data from the F15, F16 and F18 satellites. The images are downloaded in compressed format. The file used in this case study is named F16201001060040.d.peru.OIS, and can be downloaded from the IOCCG website at: <http://www.ioccg.org/handbook/Paulino/>. The file naming conventions are as follows: F##YYYYMMDDTTTT.region.*, where F## = satellite number, YYYY = year, MM = month, DD = Day, TTTT = UT time at start of ascending data, region = Peru.

The location of fishing fleets in Peruvian waters (latitude, longitude, name and time) was obtained using ARGOS satellite-tracked data. ARGOS receiver-transmitters on each vessel receive information from GPS (Global Positioning System) satellites and transmit 30 daily reports of the geographical position of each boat. This information is received, processed and distributed to various users of the system e.g. the Ministry of Production (PRODUCE), Captain and Ports Directorate of the Navy (DICAPI) and IMARPE (Sisesat).

10.3.2 GIS Analysis

The spatial and temporal variability of squid fleet was analyzed using GIS, through integration of daily fishing vessel data (derived from ARGOS) and data on the number of illuminated pixels observed off the coast of Peru (derived from DMSP-OLS). GIS can be used to generate daily, weekly and monthly thematic maps to determine the spatial-temporal dynamics of the squid fleets. Thematic maps can be used to compare the number of light pixels to the number of known vessels in the area, to determine if any unlicensed fleets are operating illegally inside the Peruvian EEZ.

For the thematic mapping, both images must be geo-referenced. For DMSP

images, this is done using algorithms developed by the National Geophysical Data Center (NGDC), Boulder, CO (Elvidge et al., 1999). ARGOS data are geo-referenced using the same projection and data as the DMSP images, so that the location of vessels (X,Y coordinates) can be compared with the satellite images. For this case study we will select one position for each boat, closest to the time of the satellite overpass.

10.4 Demonstration

The DMSP/OLS images were captured at night between 19:00 to 22:00 local time, corresponding to the time when the fleets start their fishing operations. These images have been used by researchers to understand the spatial and temporal variability of *Dosidicus gigas*. In this section will show how to process the images, and subsequently how to interpret them.

Step 1: Open the OIS image in Envi (File → open external file → DMSP - NOAA). The image has two bands (visible and thermal-infrared): the visible band has digital numbers from 0 to 63, where 63 is the maximum digital number (DN) of white pixels that represent vessel lights. In this image we can also see the lights of the main cities in Peru. DMSP/OLS images have also been used to identify urban areas (Imhoff et al. 1997, Owen et al. 1998).

Depending of the visibility, we can use images captured by the F15, F16 or F18 satellites, each of which passes over the study area at a different time. Figure 10.1 shows examples of these images. The image from satellite F15 (left) has missing data. Reception time is 17:01 (local time), and since this satellite flies in a dusk orbit it is not very useful. The image captured by satellite F16 (center) was captured at 18:04 local time, and can be considered the secondary day/night satellite. In some cases there are missing data, as can be seen on the image. Finally, the image from the F18 satellite (right) was taken at 19:47 local time. This is the primary day/night satellite for Peru, and the city lights are clearly visible in this image.

Step 2: The image we have just opened is not geo-referenced so it is necessary to rotate the image. From the "Basic tools" menu, choose rotate/flip data. A new window will open (rotation input file). From here you can select the image (→ OK). In the rotation parameters window, choose angle 270 and click "yes" in transpose (see Figure 10.2). Insert an output filename. Next, load the rotated image into a new window. This step permits rotation of the image for better visualization (see Figure 10.3).

Step 3: To discriminate between light pixels and cloud pixels, we use the linear stretch function from the menu "Image → Enhance → Linear". The lights from the cities on land can now be seen, as well as some white pixels in the sea (see Figure 10.4). Cho et al. (1999) and Kiyofuji et al. (2001) determined that the bright areas



Figure 10.1 DMSP/OLS images over the study area (0°–20°S and 70°–90°W) from satellite F15 (17:01) (left), F16 (18:04) (center) and F18 (19:47) local time (right).

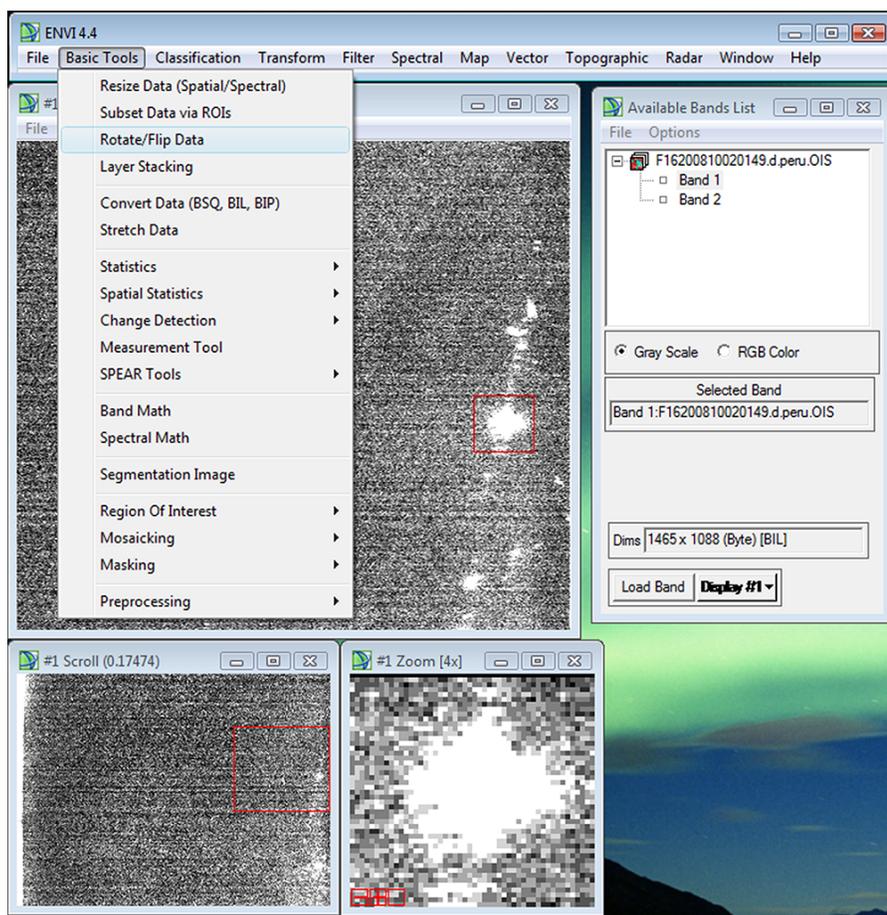


Figure 10.2 Procedure for rotating the image using the basic tools menu, with 270° rotation.

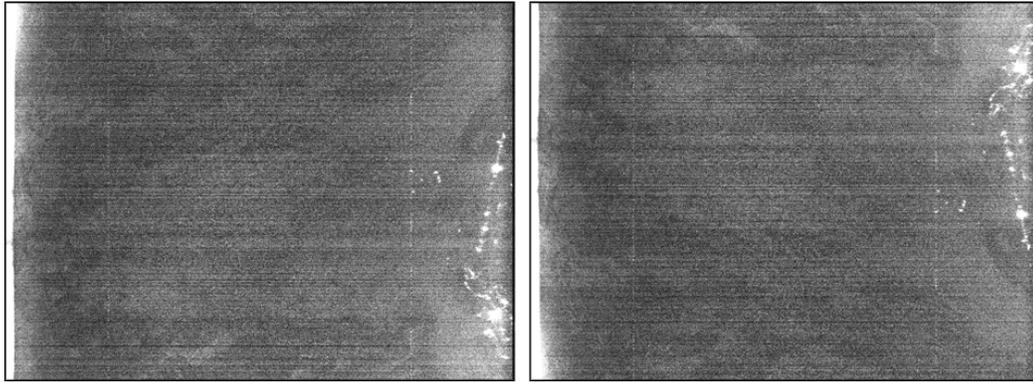


Figure 10.3 View of the study area before and after rotation, showing coastal city lights on land and some white pixels over the sea, with digital numbers ranging from 0 to 63.

in OLS images, created by 2-level slicing, were caused by the light produced by the fishing vessels. In some cases we found that pixels with a range of 18 to 30 DN could represent vessels (when compared with ARGOS data), but this does not imply that they are necessarily catching squid; they could be searching for the best fishing grounds. In other images we can find clouds with DN value of 63 during full moon, one should be careful when interpreting these images.

Step 4: To discriminate even more pixels of light, we use enhanced interactive stretching to stretch the image data using histograms (from the display group menu bar, select Enhance → Interactive Stretching). An input and an output histogram appear in the "Interactive Contrast Stretching" dialog, showing the current input data and applied stretch, respectively. Two vertical dotted lines mark the current minimum and maximum values of the stretch. For this case, choose a DN range of 15 to 63, and apply. This step will improve the image and show only the pixels of light (Figure 10.5).

The ranges of DN values can be changed from 0 to 63 using interactive stretching. You can try adjusting different ranges of DN, which will make the pixels light or dark according to the range chosen. However, each pixel maintains its digital number value. To identify the composition of the digital values of the pixels, we can perform a classification of the DN values of one bright-light area using polygons. In this area, at least 6 digital value ranges can be found, and are shown in Figure 10.6: 63 (red), 61 (blue), 56 (yellow), 55 (cyan), 49 (green) and 46 (magenta). After this processing the image will be geo-referenced using geographic projection and WGS 84 data (World Geodetic System, a reference coordinate system used by the GPS) and exported as a tiff image for visualization in GIS software.

Step 5: We used ARGOS data to determine if the bright pixel areas correspond to vessels. For this example we use the file Calamar02102008.dbf (2 October 2008,

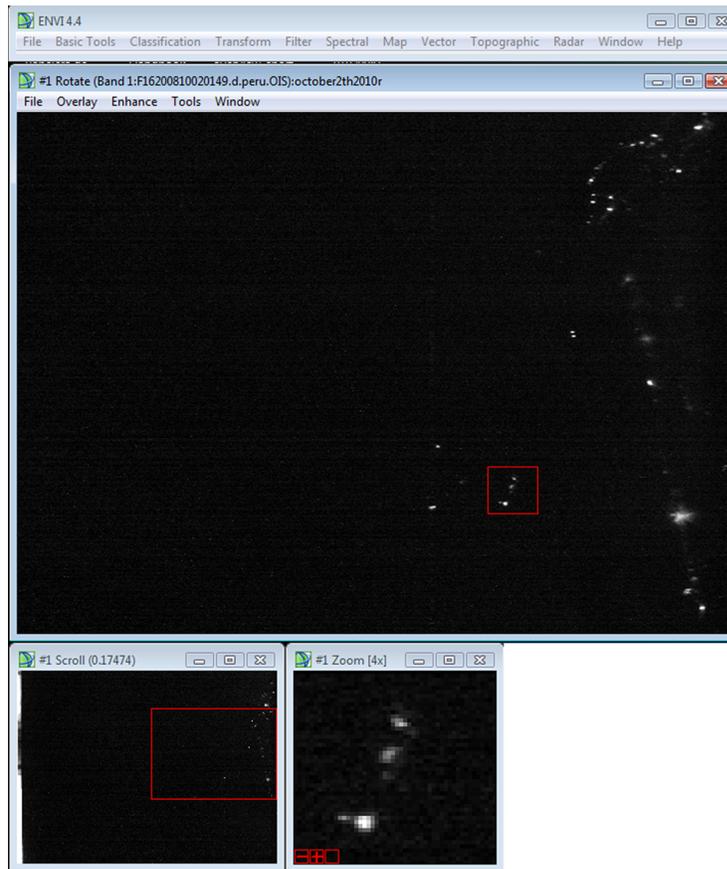


Figure 10.4 This image shows bright-light areas as white pixels that could be city lights or vessel lights.

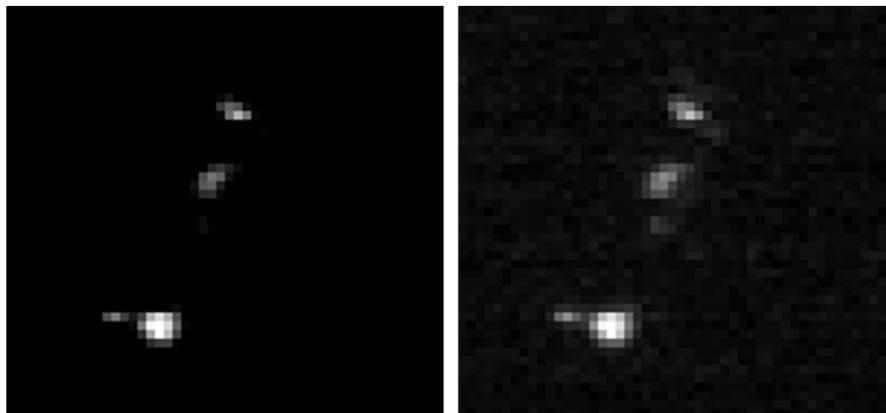


Figure 10.5 Zoomed in view showing the use of interactive stretching. We changed the DN value default from 0 to 63 (left) to 15 to 63 (right). According to this image, three boats are operating outside of the Peruvian Exclusive Economic Zone.

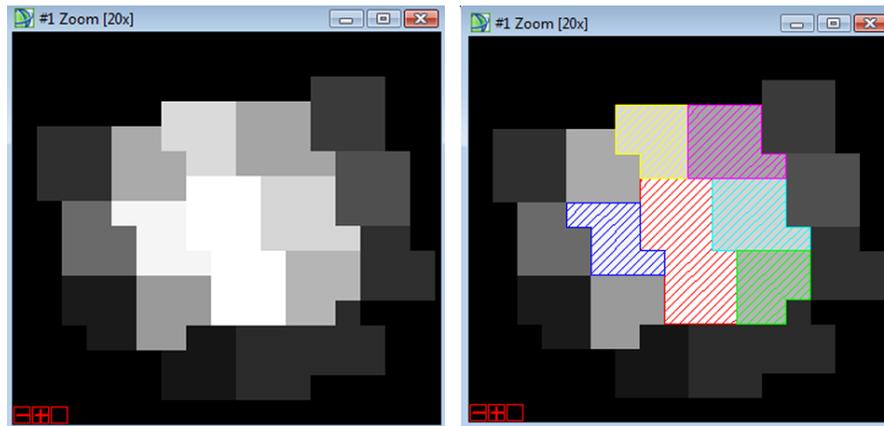


Figure 10.6 Classification of the DN value of one bright-light area as polygons: 63 (red), 61 (blue), 56 (yellow), 55 (cyan), 49 (green) and 46 (magenta).

available at <http://www.ioccg.org/handbook/Paulino/>), which contains lat/lon information of licensed fishing fleets (Figure 10.7).

Location data for the fishing vessels can be obtained using the MacPesca software developed for MapInfo, a powerful mapping and geographic analysis application. Vector files such as coast line or 200 nautical mile limit can be used in MapInfo for a better visualization of the licensed fleet positions. Load the DMS image and ARGOS data in MapInfo to compare pixel areas and number of vessels. Remember that in order to validate the ARGOS data, the ARGOS dbf file must have one position (X/Y) per vessel, taken at the same time (or close to) the time of the satellite overpass.

10.5 Training and Questions

We will now examine and interpret the processed images to verify their use in the monitoring of the squid fishery. Looking at the images from the F15, F16 and F18 satellites (Figure 10.1), please answer the following questions:

Q1: How we can distinguish pixels from vessel lights from those associated with clouds?

Q2: If we have more than one image per day, which satellite image should we use?

Q3: Do the satellites pass over the exact same area every day?

Q4: What is the minimum value used to represent the position of one vessel?

Q5: Is noise the only problem with the images?

Q6: Is it possible to know how many vessels are in a light pixel area?

Q7: Is it possible to use this kind of imagery for detection of vessels that operate

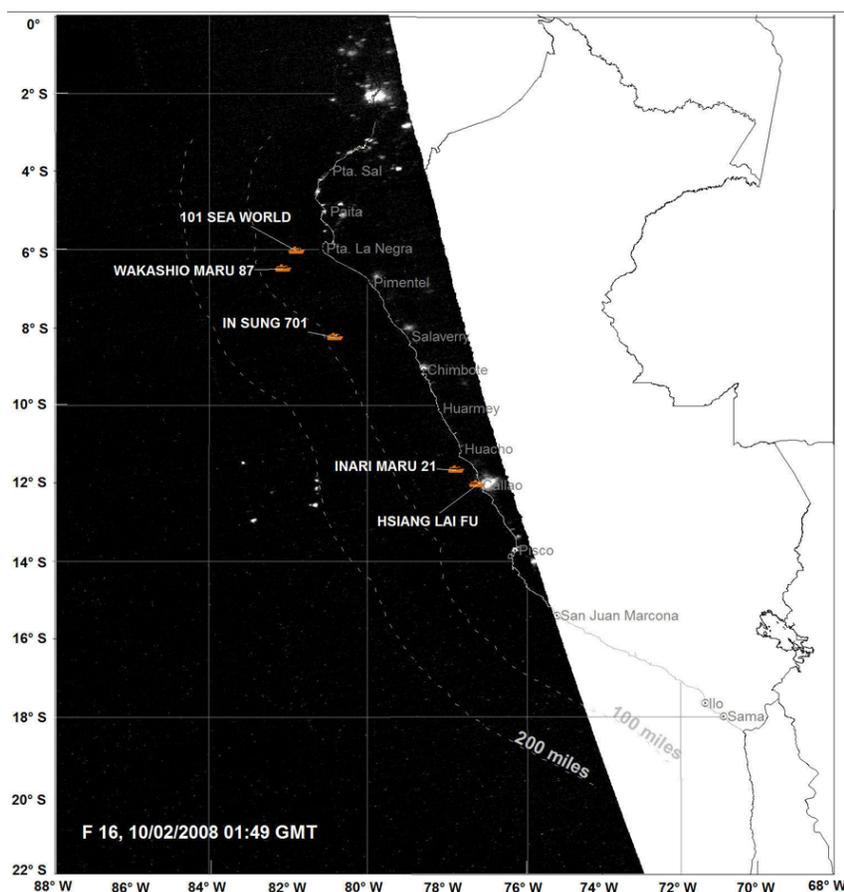


Figure 10.7 Localization of fishing vessels from ARGOS data superimposed on a DMSP/OLS image using GIS software, to compare ARGOS data with white light pixels.

outside the 200 nautical mile limit?

10.6 Answers

A1: After processing the images, we identified bright-light areas that represent vessel lights, which we adjust and classify according to DN values (Figures 10.3 and 10.4). Since we know that the digital number (DN) of saturated light pixels is 63, we can use this information to discriminate between vessel lights and clouds, applying the linear stretch function. Clouds have a DN range of 10–15 and occupy large areas, whereas fishing vessels have $DN \geq 30$.

A2: F16 is the primary satellite, but we recommend that F18 be used for over Peru, since it has better imagery over that region. Occasionally you may see images that are either completely black or white, as a result of missing data (Figure 10.1, F15

and F16 images). If there is a problem with one of the satellites you can always view the data from another one, for that night.

A3: On some nights you will get two images from each satellite and other nights you will get only one image. This is because each satellite does not fly over the exact same area every night, and depending on where the satellite is in its orbit, the number of images for each night may vary. In Figure 10.1, you can see the different overpass times of each satellite: F15(17:01), F16(18:04) and F18(19:47) local time.

A4: The DN that represents one vessel is ≥ 30 , but in some images we detected vessel lights with DN values between 18 and 30. This does not imply that they are catching squid, but it is possible that they are looking for the best fishing grounds.

A5: Noise is not the only problem with the images: a full moon can also affect the VIS image. When there is high lunar illumination ($>50\%$), there may be reflectance off the clouds in the image. In this case, it is more difficult to distinguish between cloud reflection and fishing boats, but you can still identify pixels with a DN >15 on the images. The thermal band can be used to identify clouds with greater accuracy.

A6: Kiyofuji et al. (2001) and Waluda (2004) investigated the relationship between the number of pixels (area) in the DMSP/OLS imagery and the numbers of fishing vessels, and demonstrated that fishing vessel numbers can be estimated from DMSP/OLS night-time visible images. For this research they used ARGOS data (the same kind of data that we used) for the time period 3 July to 31 December 1999.

A7: This case study demonstrates that light detection by satellite remote sensing can be used to observe spatial-temporal location of squid jigging vessels both inside and outside the Peruvian Exclusive Economic Zone.

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