Density Estimation of *Nemopilema nomurai* (Scyphozoa, Rhizostomeae) Using a Drone

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Abstract

Research to understand the distribution and density of jellyfish is actively being conducted using training ships, but this is hindered by the high cost of manpower and the limitations of the irradiation area. Unmanned aerial vehicles (UAVs or drones), however, provide cost-effective means for assessing marine animal populations. Therefore, we tested the application of UAVs in estimating jellyfish density and probed the altitude-dependent suitability of these devices. We analyzed images obtained by a drone as well as by manual counting and used ImageJ to measure the density of *Nemopilema nomurai* off Sang-Chuja Island, Jeju, South Korea. Analysis of the image obtained at altitudes of 5–120 m allowed for the identification of 2–173 individuals, while 1.49–9.09 individuals were identified per 100 m². Jellyfish density data measured by manual count and by ImageJ did not show any difference below 90 m; however, a difference was presented at altitudes of 100 m (98%) and 120 m (95%). These results demonstrate the potential of drones for jellyfish monitoring and recommend an optimal altitude for observation.

Keywords Altitude · Drone · ImageJ · Jellyfish density · *Nemopilema nomurai* · Unmanned aerial vehicle

Introduction

Recently, there have been frequent reports of mass occurrences of jellyfish worldwide, leading to an ecological imbalance in relation to the jellyfish prey (Mills, 2001; Purcell et al., 2007; Sanz-Martín et al., 2016). These swarms can damage operating nets owing to a large influx of jellyfish during fishing or cause power plants to shut down by clogging the power plant water intake (Brierley et al., 2001; Purcell, 2005). In addition, the nematocyst toxin produced by the jellyfish, especially *Nemopilema nomurai*, kills fish caught in the nets, causing a decline in the commercial value of fish (Kawahara et al., 2006). Because of the negative effects caused by occurrences of the jellyfish, there have been many studies on quantitative estimation of jellyfish (Brodeur et al., 1999; Kinoshita et al., 2006). Most studies on movement and quantitative

estimation aimed to identify the ecological characteristics of jellyfish and prevent damage from the use of traditional observation methods such as visual observation or via fishing vessels (Purcell et al., 2007). However, because traditional observation methods require significant amounts of funds and manpower, quantitative evaluation has been limited. Hence, the improvement of fishing gear is required for more efficient quantitative analyses (Lynam et al., 2004). Moreover, as the population of jellyfish increases rapidly every year (Brodeur et al., 2002; Pitt & Lucas, 2014; Richardson et al., 2009), the annual or long interval jellyfish observation approach may not be appropriate (Isinibilir et al., 2010). However, unmanned aerial vehicles (UAVs) or drones enable the automatic capture of images over a wider area, which can then be used for analysis or classification (Horton et al., 2019; Kelaher et al., 2019). Thus, this not only reduces research time and cost, but also improve the accuracy of jellyfish quantification (Schaub et al., 2018).

The jellyfish, *Nemopilema nomurai*, has been found in Asian coastal areas, such as the Yellow Sea, the East China Sea, the East Sea of Korea (the sea of Japan), and the Seto Inland Sea of Japan (Kawahara et al., 2006), and the

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distributions of the jellyfish are known to be related to the direction and intensity of the current, especially the Tsushima Warm Current flowing from the East China Sea to the East Sea of Korea (Uye, 2008; Yoon et al., 2008). In this study, for development of the monitoring studies on the Jellyfish, drone images were collected, and based on obtained results, we evaluated the possibility of the use of the drone to estimate the density of *N. nomurai*.

Materials and Methods

Image Collection Using a Drone

A field survey using a drone was conducted for quantifying the density of *Nemopilema nomurai* swarms at 12 intervals of altitude between 5 and 120 m off Sang-Chuja Island (33°57'43" N, 126°17'45" E), Jeju, South Korea (Fig. 1) at 4 pm on July 5, 2020. To facilitate marine mapping, sampling was performed at 4 pm under low wind conditions because at noon, and the glare from the water surface makes it difficult to identify the jellyfish (Fig. 2).

The flight was conducted entirely on land, maintaining a constant visibility distance according to regulations. The drone used was an off-the-shelf DJI MAVIC 2 Pro (DJI Technology Co, China) flown manually in GPS mode. We had created 12 height intervals between 5 and 120 m, and the drone was stopped at each interval to capture a GPS-tagged image using a 20 MP camera in capture mode. To reduce the reflection of the sun, the image was taken at a 90° angle. The battery of the DJI MAVIC 2 Pro drone provides up to 28 min of flight time, and this experiment

Fig. 2 An image of *Nemopilema nomurai* taken at noon, 30 m altitude

required 20 min of flight time. No automated flight path software was used. In addition to this, jellyfish were observed through visual observation, but the maximum distance was 10 m. While up to five individuals were identified using this method, visual observation data were not included.

The ImageJ program (1.40 s, National Institutes of Health, Bethesda, MD, USA) was used to confirm the density of the jellyfish. The ImageJ program is a widely used image processing platform, and can be used for image analysis, from image processing to data comparison with multiple imaging systems. It is developed on an open architecture platform that provides a variety of extension tools and plugins for data collection, analysis, and processing are developed in the built-in editor and compiler (Igathinathane et al., 2008). The image file was converted to an 8-bit image and manually sorted into the color

Fig. 1 Map showing the study site, the Chuja Island of Korea

Fig. 3 Jellyfish images relative to the altitude of the drone image, and the corresponding image when converted by ImageJ: (a–l) images captured by the drone: **a** 5 m altitude, **b** 10 m altitude, **c** 20 m altitude, **d** 30 m altitude, **e** 40 m altitude, **f** 50 m altitude, **g** 60 m altitude, **h** 70 m altitude, **i** 80 m altitude, **j** 90 m altitude, **k** 100 m

altitude, and **l** 120 m altitude (**m–x**) images converted by ImageJ: **m** 5 m altitude, **n** 10 m altitude, **o** 20 m altitude, **p** 30 m altitude, **q** 40 m altitude, **r** 50 m altitude, **s** 60 m altitude, **t** 70 m altitude, **u** 80 m altitude, **v** 90 m altitude, **w** 100 m altitude, and **x** 120 m altitude

thresholds to accurately identify the jellyfish, while unrelated particles were eliminated (Fig. 3). Particles on the image were counted using the image analysis feature, which is a widely used method of analysis (Igathinathane et al., 2008; Rishi Kumari & Narinder Rana, 2015).

Statistical Analysis

The *t*-test was performed using GraphPad version 8.0 (GraphPad Software, San Diego, USA) to compare the jellyfish population density determined by ImageJ and via manual observations. Values of $p < 0.05$ were considered to be statistically significant.

Results and Discussion

In the images at each altitude, 2 to 173 individuals were identified, and the converted individual number per 100 m² was 1.49 to 9.09 (Fig. 4). From a drone image taken at an altitude of 120 m, a total of 167 individuals were counted, which represented the highest number of individuals observed at any height interval. However, when we converted the data to the number of individuals per area, the density was highest at the altitude of 5 m (9 [n/100 m²]) (Table 1). At an altitude of 120 m, many jellyfish individuals could be counted in a short time, but the accuracy was relatively low. The accuracy of jellyfish identification can be problematic when retrieving the images captured by the drones (Fig. 5). If we enlarge an image taken at an altitude of 120 m, the resolution is lowered, making identification more difficult than at lower altitudes. The results revealed that it might not be possible to distinguish between jellyfish and unnecessary particles in photographs

taken from an altitude of 120 m or higher. Consequently, when using a drone in the field, light reflection, wind and altitude should be considered. For instance, excess light is reflected off the water surface at noon, making it difficult for drones to capture distinct images (Fig. 2).

There was no significant difference in the density of jellyfish determined by ImageJ (1.40 s, National Institutes of Health, Bethesda, MD, USA) and that measured manually (*t*-test, $p > 0.05$). Although the accuracy of the jellyfish density estimated using the ImageJ program was approximately 95% or more compared to the manually observed population, it is necessary to quantitatively verify the difference in the efficiency of photographing jellyfish according to altitude (Fig. 4). At an altitude of 10 m, the observation area was 87 m² and quite close to 100 m², which is considered as the standard area for estimating the number of individuals. The converted individual number per 100 m² was also close to the observed value (Table 1). Uye et al. (2010) reported the number of individuals of *N. nomurai* visually observed in the East China Sea from 2006 to 2010 at 1.97 (n/100 m²) in 2006, 3.17 (n/100 m²) in 2007, and 0.02 (n/100 m²) in 2008. Additionally, the National Institute of Fisheries Science (2019) reported that the jellyfish density around Jeju Island in July was 0.006–15.38 (n/100 m²); our results are consistent with the estimated values. Visual observation using boats requires more manpower and time, while visual observation via ships is generally considered as expensive. However, drone surveying provides a means to generate high-quality monitoring data at a relatively low cost. Furthermore, the drone image can more easily and effectively estimate the density over a larger area using the ImageJ analysis program, thereby conserving time. This suggests that the uses of drones have sufficient advantages to replace traditional research methods such as troll surveys and visual observation for future estimations of jellyfish density.

Conclusion

Unmanned aerial vehicles (UAVs or drones) provide a cost-effective technique for evaluating large jellyfish (*Nemopilema nomurai*), showing the possibility of easier counting with ImageJ. At an altitude of 10 m, the observation area was 87 m² and quite close to 100 m², which is considered as a standard area for estimating the number of individuals. According to our research, both the efficiency of observation with a drone and observations according to optimum altitudes have sufficient advantages to replace traditional observation methods.

Fig. 4 Manual and ImageJ count of the individual jellyfish (*Nemopilema nomurai*) according to altitude and area

Table 1 Density of jellyfish and observed area estimated manually and according to the altitude of the drone

Altitude (m)	Area (m ²)	Individuals		100 m ²	
		Manual count	ImageJ	Manual count	ImageJ
5	22	2	2	9.09	9.09
10	87	4	4	4.6	4.6
20	338	8	8	2.37	2.37
30	758	21	21	2.77	2.77
40	1323	33	33	2.49	2.49
50	2171	38	38	1.75	1.75
60	2965	42	42	1.42	1.42
70	4186	56	56	1.34	1.34
80	5173	76	76	1.47	1.47
90	6646	98	98	1.47	1.47
100	8489	118	116	1.39	1.37
120	11,594	173	165	1.49	1.42

Fig. 5 Image resolution relative to altitude

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Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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