ARTICLE IN PRESS

Fisheries Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Short communication

Rapid biomass and size-frequency estimates of edible jellyfish populations using drones

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ARTICLE INFO

Handled by George A. Rose

Keywords:
Scyphozoan
Fisheries
UAV
Cnidarian
Estuary
Monitoring

ABSTRACT

There has been an international increase in the demand of edible jellyfish products, but traditional means of monitoring jellyfish populations using fisheries techniques may not be ideal. The boom-and-bust nature of many jellyfish populations means that biomass estimates used in monitoring need to be rapid and accurate, and assessing the temporal and spatial variability of jellyfish populations can also help determine their ecological role. Here we used off-the-shelf drone technology coupled with automated image processing to show that densities, size measurements and biomass estimates of an edible jellyfish, the Jelly Blubber *Catostylus mosaicus,* can be rapidly estimated over much larger areas than traditional field sampling and without requiring fishing effort. Estimated biomass within Smiths Lake, New South Wales, Australia was roughly 350 kg per hectare, and size frequency distributions were skewed towards larger specimens compared to previous studies in other locations. Drone counts were similar to a visual census which provides further evidence that this rapid and relatively automated method has potential to be used more widely in ecological monitoring.

1. Introduction

Jellyfish as a group of organisms are garnering increasing interest from the community at large. This is due to the widespread, if flawed, perception that jellyfish blooms are becoming more common (Lynam et al., 2006; Mills, 2001; Purcell et al., 2007; Sanz-Martín et al., 2016), the expanding global jellyfish wild and aquaculture fishery (Brotz and Pauly, 2016; Dong et al., 2009; Omori and Nakano, 2001), and the slow realization that they have an important ecological role (Fleming et al., 2015; Houghton et al., 2006). However, due to the rate at which jellyfish populations expand and collapse (Pitt et al., 2014), fisheries and conservation management approaches of jellyfish populations relying on annual or bi-annual stock assessments may not be appropriate (Kingsford et al., 2000). Instead, monthly or even weekly assessments may be necessary, yet fieldwork involving manual visual counts is not appropriate at these timescales.

In the last decade, the development of remote operated vehicles and unmanned aerial vehicles (UAVs, or drones) has led to the development of low-cost survey techniques for large numbers of organisms using novel metrics (Colefax et al., 2017; Kiszka et al., 2016). In addition, unlike traditional survey techniques, the use of drones can allow automated image analysis and categorization (Ratcliffe et al., 2015), which can reduce survey time, cost, and increase the accuracy of assessments due to the larger area covered. These attributes are desirable for jellyfish surveys, and indeed recent work has explored the possibility of using drones to measure jellyfish aggregations (Schaub et al., 2018). While effectively demonstrating that drones were a useful tool for jellyfish research, the approach of Schaub et al. (2018) was aimed at describing relatively small agglomerations of non-commercial jellyfish in deeper waters. Because their approach was not fisheries-focused, information on size-frequency distributions regularly used by fisheries and ecological monitoring were not determined. A drone survey method requiring only the drone operator and a spotter, which could be conducted from the shore and still acquire relevant population data would be preferable.

The Jelly Blubber (*Catostylus mosaicus*) is a widespread species of jellyfish found in the Indo-Pacific which is commercially harvested in Australia along the Queensland and New South Wales coastlines. While current estimated Australian catch estimates of ~4 tons per year are relatively low compared to other jellyfish fisheries (Brotz, 2016), difficulties in managing populations of *C. mosaicus* were highlited as one of the barriers to a more developed fishery (Snape, 2003; Victoria, 2002). The medusae of this species can occur in high densities in estuaries, and they are known to have an important role in inorganic nutrient cycling in these environments (Pitt et al., 2005). These jellyfish are a conspicuous white or blue colour, and primarily occur within the first meter from the surface (Pitt and Kingsford, 2003). Their biology has been well-studied (Peach and Pitt, 2005; Pitt et al., 2008), and size-

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https://doi.org/10.1016/j.fishres.2018.06.010
Received 3 May 2018; Received in revised form 11 June 2018; Accepted 12 June 2018

Please cite this article as: Raoult, V., Fisheries Research (2018), https://doi.org/10.1016/j.fishres.2018.06.010

weight relationships are known (Pitt and Kingsford, 2003); these characteristics make them an ideal candidate to expand the use of drones to assess biomass, densities and size-frequencies of jellyfish for the purpose of fisheries monitoring.

This study aimed to determine whether drone imagery could be used to effectively measure biomass, size-frequency distributions, and density of Jelly Blubbers in an estuary environment. Specifically, the aims were to 1) assess if the inclusion of coastal structures was necessary, and 2) see if automation of counts and sizes was possible for biomass calculations. The expected outcome was to present an approach that could be used by fisheries managers and ecologists on a wider scale using a number of species of jellyfish.

2. Materials and methods

2.1. Field sampling

Field sampling occurred on the morning of the 6th of August 2017 in Smiths Lake, NSW, Australia (152.519E 32.393S), roughly 270 km North of Sydney. Smiths Lake is an Intermittently Closed and Open Lake or Lagoon (ICOLL) typical of south-eastern Australia (Roy et al., 2001). Smiths Lake is predominantly closed in dry periods, with an average depth of ~5 m, and a fluctuating surface area of ~10 km^2 (Everett et al., 2007; Strotz, 2015). The lake is divided into separate zones as part of the Port Stephens Great Lakes Marine Park: a sanctuary zone on the western end, a general use zone in the middle, and a habitat protection zone on the east side near the entrance.

Sampling occurred in the morning to fly in conditions with less wind that are more conducive to marine mapping (Joyce et al., 2018). Lower wind would also reduce wave action and surface reflections that would make it more difficult to identify jellyfish and for automated image analysis to separate jellyfish from surface clutter. A boat carrying the driver, drone pilot, and spotter was driven out into the lower end of the general use zone of the lake. Flights were conducted entirely from the boat to reduce flight times, and maintain constant line-of-sight as per federal regulations. The drone used was an off-the-shelf DJI Phantom 3 Pro flown in GPS mode manually. At an altitude of 70 m, a linear transect roughly 500 m long and 150 m wide running west to east from the boat towards the sea at a speed < 10 km/h was recorded via rapid 12 M P image capture mode, which captures a GPS-tagged image every two seconds at an 80° angle to reduce sun reflection. Previous testing has found at a low flight speed the rapid capture mode easily produces high amounts of image overlap greater than 80% required for reliable image alignment. A height of 70 m was chosen as a compromise that allowed easy identification of large jellyfish while covering a large area, while still providing 0.057 m per pixel resolution. While flying at this altitude meant that small medusae < 10 cm bell diameter were unlikely to be visible, since the mass of *C. mosaicus* increases exponentially with bell diameter and size distributions are usually normal (Pitt and Kingsford, 2003), measuring larger medusae would produce similar estimates of total biomass. The resulting transect collected 12 images in total (Fig. 1). Since this was a preliminary study, we only captured a 'small' transect, as the majority of available flight time was taken conducting more traditional U-shaped search patterns at lower attitude, which were not ideal for these purposes since small movements from the jellyfish would prevent successful image alignment.

2.2. Image processing

Before the full transect could be reconstructed and orthorectified, images were processed in open-access imaging software GIMP 2V. 2.8.2 to increase the ease of alignment. All images were processed using the 'batch' function, and the images were posterized to 3 colours in total. The benefit of this processing is that it effectively eliminates clutter from waves, wind, and sun reflections that can make alignment difficult if conditions are not ideal (Gonçalves and Henriques, 2015).

Processed images were imported into Agisoft Photoscan V. 1.3.4, which automatically corrects images for lens distortion and incorporates GPS-data from drone photography. Images were processed in a format similar to many coral reef studies such as Raoult et al. (2016), but image alignment at the 'medium accuracy' setting was easier due to geo-referencing, relatively small numbers of images, and no need for extensive 3D modelling. A high-quality orthomosaic was exported from the reconstructed model, which also estimates pixel resolution, and Agisoft also extrapolates the altitude of the aligned cameras (here ~70 m) and their GPS position. The total area of the transect, which could be used to assess densities, was calculated using the 'measure area and volume' tool.

The orthomosaic was converted into a JPEG file and imported into ImageJ V. 1.50i, an open-access image processing program. The transect was transformed into an 8-bit image, and the colour threshold was manually aligned to correctly identify medusae and exclude unrelated surface clutter. This produced an image where the water surface was black and the jellyfish were bright white. The boat, which was

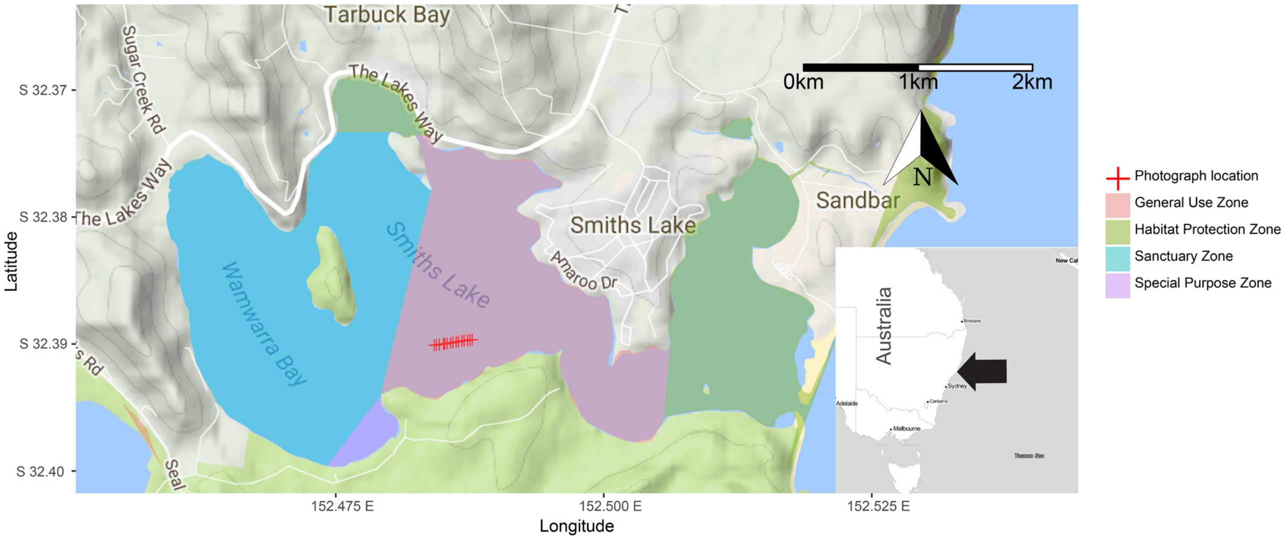

Fig. 1. Map of Smiths Lake, NSW, Australia with image capture locations used to construct jellyfish transect (red '+' signs) and different habitat protection zones. Inset of the east coast of Australia with the location of sampling highlighted with a black arrow (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).