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A novel in situ method for estimation of the carapace length of sheltering spiny lobsters, *Panulirus japonicus*, via stereo photography

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ABSTRACT

We developed a practical and reliable non-invasive method for estimating the carapace length of the spiny lobster, *Panulirus japonicus,* hidden in shelters. The method estimated the carapace length (CL) from multiple reference body parts measured from images taken using compact stereo cameras, based on predetermined allometric relationships. Two versions of the method to estimate CL were tested, one from only non-sexual reference lengths (Method I) and the other from all including sexually differential reference lengths through determining sex (Method II). Fifteen reference lengths, consisting of 4 distances between characteristic points on the cephalothorax, and 11 segment lengths of appendages, were measured using stereo photogrammetry for 53 spiny lobsters in outdoor tanks, and all except the distance between the frontal horns provided reasonably accurate regression models to estimate CL (relative errors at 95% prediction intervals ranging within ± 15%) including sexually differential models for 10 appendage reference lengths. A laboratory test with 39 different lobsters in artificial dens showed that Method II enabled correct sexing for > 70 mm CL and provided CL-estimates for 95% of the lobsters with absolute relative errors < 10%, while Method I provided a slightly lower acquisition percentage (87%) and precision (maximum absolute relative error = 12%). Field tests demonstrated that, flash photography produced sharp images suitable for image processing without evoking escape behavior, and Method II could achieve a similarly high acquisition percentage (ca 90%) of CL-estimates, validating the practicality of this non-invasive method in the field.

1. Introduction

Size determination is essential for evaluating the biomass (Brock, 1954; Friedlander and DeMartini, 2002), growth (Fournier et al., 1990), and age (Berkeley et al., 2004; Tanaka, 1953; Wetherall et al., 1987) of organisms, as well as understanding intra- and interspecific interactions (Ling et al., 2009; Scharf et al., 2000). For motile and cryptic animals, catch-based measurements of size are frequently restricted due to the difficulty of catching individuals as well as potential ecological consequences of capturing and handling. Furthermore visual estimates must always be validated and calibrated with catch-based measurements for each diver on each dive. The reliability of measurements depends on accuracy (bias of mean errors) and precision (variability of individual errors). To our knowledge, there are no non-stressful, reliable methods for measuring the size of such animals at present.

Spiny lobsters (Palinuridae) are key predators of benthic invertebrates, including dominant mussels on rocky coasts and sea urchins that overgraze macroalgae; however, lobsters must be large to ensure successful predation (Robles et al., 1990; Tegner and Levin, 1983). Spiny lobsters are nocturnal and remain hidden in shelters, such as the interstices of rocks and the crevices of reefs during the day (Phillips et al., 1980). Lobster size is generally represented by carapace length (CL); however, this body part is not visible in its entirety when lobsters are in their shelters. Thus, at present, it is necessary to catch lobsters to measure the CL accurately. Lobster CL has been estimated from visual observations by divers in field studies (e.g., Babcock et al., 1999; MacDiarmid, 1991; Shears et al., 2006); however, visual estimates can include systematic errors by individual divers. Thus, estimates should be validated or calibrated with catch-based measurements for each diver on each dive. Studies on diver-estimated sizes of other marine wildlife, such as reef fish length, have also demonstrated that remote visual measurements by divers have low precision (Harvey et al., 2002).

Stereo photogrammetry is a potential alternative technique for measuring the precise length of marine organisms. Stereo length measurement techniques, with dual video or still-camera systems, have

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been studied extensively in terms of accuracy and precision, and are increasingly used as survey tools for various aquatic organisms, such as pelagic (Santana-Garcon et al., 2014), demersal (Moore et al., 2010), and reef (Harvey et al., 2001, 2002) fishes, shellfish (Shortis et al., 2000), corals (Bythell et al., 2001), and deep-sea epibenthic megafauna (Dunlop et al., 2015). Estimates of fish length made with a stereo-video system were demonstrated to be superior to those determined visually by divers, with respect to both accuracy and precision (Harvey et al., 2001). These techniques successfully provide highly accurate measurements of the distance between 2 extreme ends of body outlines, such as the snout to fork length in fish. However, stereo photogrammetry has been little used to measure cryptic animals (but see Scharf et al., 2000), such as spiny lobsters, which remain hidden in shelters, and rarely during daytime display their entire body length or abdomen. Therefore, to apply stereo photogrammetry to the measurement of lobster CL successfully, the problem of how to determine the CL from images of other body parts needs to be resolved, as well as accounting for the low-light levels experienced in lobster shelters. Furthermore, conventional dual video and still-camera systems are not compact, so they are impractical to use in the confined spaces of lobster habitats.

In the present study, we present a practical and reliable technique for measuring the CL of the Japanese spiny lobster, *Panulirus japonicus*, without the requirement of physical capture, using stereo cameras. The accuracy, precision, and efficiency of the technique were examined under simulated field conditions in the laboratory and in the field. Our results are expected to provide a novel way of measuring marine species in the field, which could help improve the management of cryptic fisheries resources.

2. Materials and methods

2.1. Stereo cameras and photogrammetry

The stereo cameras used in this study were the Fujifilm FinePix Real 3D W1 and W3 (Fig. 1), which are compact digital stereo cameras equipped with two lenses 75 mm apart, that capture 2 images simultaneously at a resolution of 3648 × 2736 pixels. The focal length of the cameras is 6.3 mm at the widest angle position used in the present study. The strict specifications of the two points on the right and left images allows the distance to be measured between the two points using 3-dimensional (3-D) distance measurement software (AVSMeasure3D-F, Applied Vision Systems, Tsukuba, Japan), based on geometric camera parameters. The parameters were determined by calibrating cameras housed in waterproof cases (dimensions: 150 × 97 × 60 mm; Fig. 1) in seawater. Underwater photographs of a specially designed calibration board with a grid of dots (Applied Vision Systems) were taken from a minimum of 6 different angles and distances, and then the camera parameters were automatically determined using the images by means of the calibration software (AVSCalibforFuji3Dcam, Applied Vision Systems). The principle of calibration can be found in Bouguet (2013). The zoom function was not used to maintain the same geometric camera parameters during measurements. Instead, the camera focus was set to the widest angle. The accuracy and precision of this calibration system was tested using ten 20-mm scale bars attached to a 28 × 28 × 28 cm cubic frame consisting of 8 sub-cubic frames (Fig. 2). The scale bars were attached at different locations on the front-facing surfaces of the sub-cubic frames. The FinePix Real 3D W3 camera was used. Images of the cubic frame were taken along a 60 cm long line placed 40 cm in front of the frame (thus the distance between the camera and scale bars was ca 40–80 cm). The photogrammetric measurements of the scale bars showed only negligibly small errors (mean ± SD: 0.04 ± 0.13 mm; maximum absolute error: 0.40 mm; $n = 30$), irrespective of the distance to the object or of the sharpness of the images, if both ends (marked with crosses) of the scale lines could be specified.

2.2. Definition of CL

CL was defined as the distance from the middle of the rostral horns to the dorsal posterior edge of the carapace (Fig. 3). Initially, we measured a standard CL as the distance from the posterior margin of the eye socket to the posterior margin of the carapace on a line parallel to the dorsal midline. However, this measurement of CL was nearly equal to, or slightly shorter than, the final definition, and was difficult to measure accurately; thus, we converted this measure to the final definition of CL using the regression equation: $y = 1.012x$ ($n = 28$, $r^2 = 0.99$).

2.3. Determination of the estimation model

The developed method estimated CL from lengths of other body parts measured with stereo photogrammetric techniques, via predetermined allometric equations: $Y = aX^b$, where Y is the CL (mm), X the reference length (mm), and a and b are constants. To enable accurate identification in the photographic images, the reference lengths needed to be photographed in situ, as well as have clear-cut edges. Fifteen reference lengths (Fig. 3) were tested as potential candidates: (1) the distance from the middle of the rostral horns to the proximal end of the “groove” between antennular pads (DRA); (2) the distance between the proximal ends of the eyestalks (DBE); (3) the distance between the posterior margin of the eye socket to the lowest posterior

Fig. 1. Fujifilm FinePix Real 3D W1 (right) and W3 (left) stereo cameras housed in waterproof cases.