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Spots on Sides of Giant Sea Bass (*Stereolepis gigas* Ayres, 1859) are Likely Unique to Each Individual

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The giant sea bass (*Sterolepis gigas* Ayres, 1859; hereafter GSB) is a large and presumably keystone nearshore reef species found from California, USA to southern Mexico, including the Gulf of California. Giant sea bass were severely overfished in the twentieth century leading to local extinctions. Restrictions on harvest off California have led to at least a mild resurgence in the population (Pondella and Allen 2008; House et al. 2016) and, based on a genetics study, an effective population size of perhaps 500 individuals off southern California and northern Baja California (Chabot et al. 2015). However, there has been no direct assessment of their numbers off California.

From at least spring through fall, it is likely that most, if not all, GSB inhabit nearshore waters to depths of perhaps 30 m (Love 2011). We are interested in determining if recreational divers can assist us in determining the abundance of this species in California waters as divers can often easily approach and photograph these fish. If there was a way of identifying individuals underwater from still or video images, images from divers could help us determine the number of individuals in the sampling area. This process would require individuals to have unique markings. Giant sea bass of all ages have dark spots or blotches on their heads and flanks and these might be idiosyncratic and thus useful in identifying individuals. Among fishes, markings of various sorts, including spots and stripes, have been shown to be unique to individuals and thus may be of value in determining species abundances (Meekan et al. 2006; van Tienhoven et al. 2007; Claydon et al. 2010; Giglio et al. 2014).

To determine if we could use the spotting on the flanks of GSB as unique markers, we made preliminary observations of GSB spot patterns at the Aquarium of the Pacific in Long Beach. Here we took photographs of the three GSBs (two adults and one likely subadult) on 18 June, 1 July and 3–4 July 2014. We photographed these fish at least hourly for 12 hours (18 June, 1 July) or over 24 hours (3–4 July). Over the past few years, pattern recognition software, such as the Individual Identification System (I3S Spot 4.02; www.reijns.com/i3s, hereafter referred to as I3S), have been developed to partially automate the process of reviewing images and helping to identify individuals (van Tienhoven et al. 2007). We used I3S to compare spots on the sides of each individual and between individuals. Using both this software and visual comparisons, we found: 1) the spot patterns did not change over the 12 or 24 hours surveyed, 2) the spot patterns were unique to an individual, and 3) each pattern was unique to a side of each individual (i.e., the spot patterns were asymmetric). Soon after these analyses, we acquired from Ms. Sandy Trautwein (Aquarium of the Pacific) images taken in 2003 of two of these Aquarium of the Pacific fish. Again, using I3S and a visual inspection, we determined that the spot patterns of these individuals were identical to those observed on these

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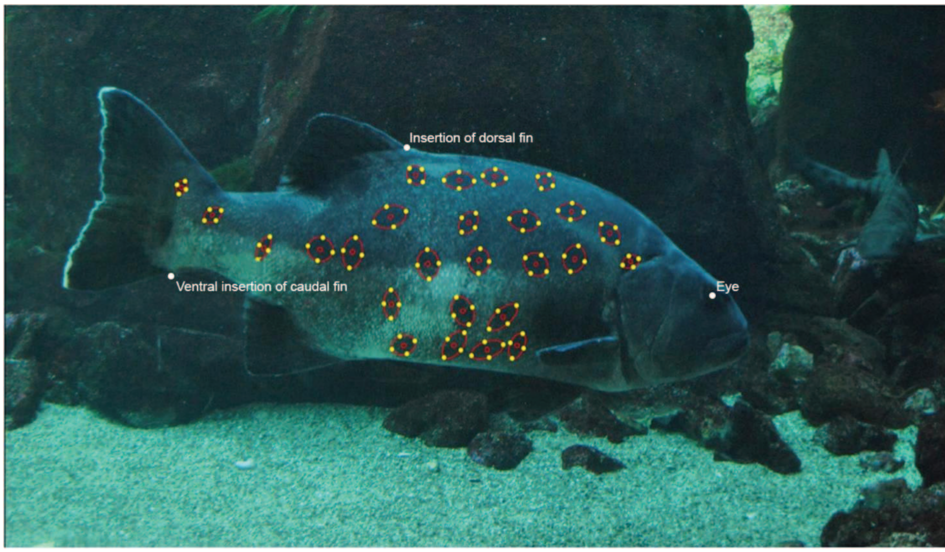

Fig. 1. An example of the spot annotations used in the I3S program. Note the position of the three reference points.

individuals in 2014. This implies that the spot patterns of adult GSB may not change over time.

Given these preliminary results we determined to answer the following questions:

1) Can I3S be used to identify individual GSB and, if so, what factors affect the ability of I3S to help identify individuals?
2) Do individual GSB have unique spot patterns?

Note that this study was limited to adult and subadult fishes. Although young red or orange fish have black spotting, they were not included in this analysis.

We created a database of known "individuals." Because each side has a unique spotting pattern in this context every fish consisted of two "individuals." For this study, we accumulated images of 35 individuals, based on 12 captive and 23 wild individuals. We validated that each wild fish was indeed unique by using scarring or other body marks. Each individual was represented by up to three unique images. When using I3S we first chose three reference points that were used for every individual. In the case of GSB, the reference points were 1) the eye, 2) the origin of the soft dorsal fin, and 3) the ventral origin of the caudal fin (Fig. 1). Then, in I3S, after marking these reference points, we annotated each spot by forming a circle around each mark (Fig. 1).

Out of 124 total tests (testing only individuals with two or more images in the reference library) we found that 93.5% of the tests ranked at least one other image of the same individual in the top 5 best matches and 94.4% of the tests ranked at least one other image of the same individual in the top 10 best matches. It is important to note that I3S does not determine a match automatically; rather the user examines the top images ranked by the software and manually determines if a match exists. In this study, I3S suggested

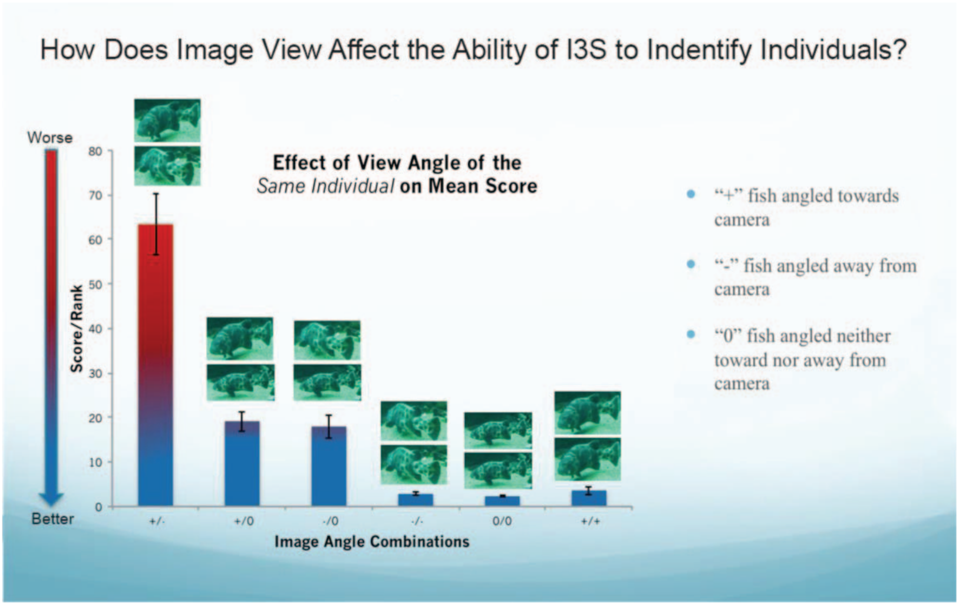

Fig. 2. The effect of comparing two images of the same fish angled differently. Higher scores imply a lower probability that the two images are of the same individual.

a correct match (placing a true match in the top 10 ranked image results) 95% of the time.

In these early tests, it was apparent that the angle at which a viewer observed an individual could affect the scores generated by, and thus the overall accuracy of, the I3S program. To test what angles were useful we sorted the scores generated by I3S for three different viewing angle combinations of the same individual. We determined that the effect of viewing angle was a large factor affecting the ability of I3S to correctly characterize two images as having come from the same individual (Fig. 2). We found that comparing images of a fish with identical orientation yielded the most accurate scores and scores increased (that is became less accurate) when the two orientations diverged. At the extreme, the highest (poorest) scores were generated when an image of a fish whose head was pointing slightly towards the camera was compared with an image of that fish with its head pointed slightly away from the camera.

We were also interested in how I3S would handle comparisons of two images where one image was of a fish perpendicular to the camera and the other was of the same fish angled to or away from the camera (Fig. 3). We found that slight divergences from the perpendicular yielded low (more accurate) scores, but that the chances of false negatives (images of two identical individuals mistaken for two separate individuals) increased as the angle increased. In particular, comparing a perpendicular image with one that was almost tail-first yielded very poor scores.

We created a database consisting of images of 16 unique individuals. Of these, 12 were captive individuals and four were photographed in the wild and identified by unique scarring. We decided to address this question by comparing the scores generated by I3S for "matching image pairs" with the scores generated for "non-matching image pairs."

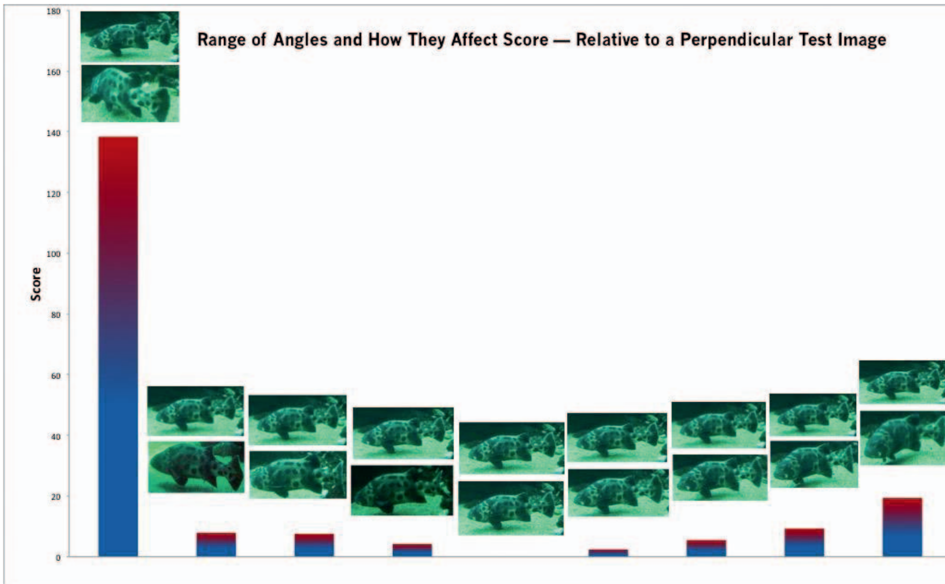

Fig. 3. Comparing the effect of two images of the same fish where one image is perpendicular to the camera and the other is variously angled away. Higher scores imply a lower probability that the two images are of the same individual.

"Matching image pairs" describes two different images of the same individual being compared with one another (72 different combinations in this study). "Non-matching image pairs" describes two different images of two different individuals being compared to one another (1568 different combinations). In this analysis we found that the populations of scores for "matching image pairs" and "non-matching image pairs" were significantly different Welch's t-test (F Ratio = 440.1338, DF = 1, Prob > F = <0.0001, t-test = 20.9795). The upper 95% confidence interval for the scores of "matching image pairs" (score = 29.3) falls well below the lower 95% confidence interval for the scores of "non-matching image pairs" (score = 105.7) (Fig. 4). Because a statistically significant difference exists between the two populations of scores generated, we can treat the spots on these fish as truly unique to the individual. In addition, the upper 95% confidence interval for the scores of "matching image pairs" also provides us with a practical cut-off score (30) for identifying matches in the program.

In summary, we have shown that using I3S can be an effective tool in helping researchers compare underwater images of unknown GSB. This software is particularly useful in winnowing through large numbers of images and providing the most likely matches. Our research implies that the spots on adult GSB are likely unique to each fish (and each side of each fish) and that these marks can aid in both creating population estimates and in understanding the species' migrations and movements. In addition, the relative ease with which recreational divers can provide us with usable images opens up this research to citizen scientists. Indeed, it is our goal to use this technique and the large number of recreational divers in southern California to census the giant sea bass population in this region.

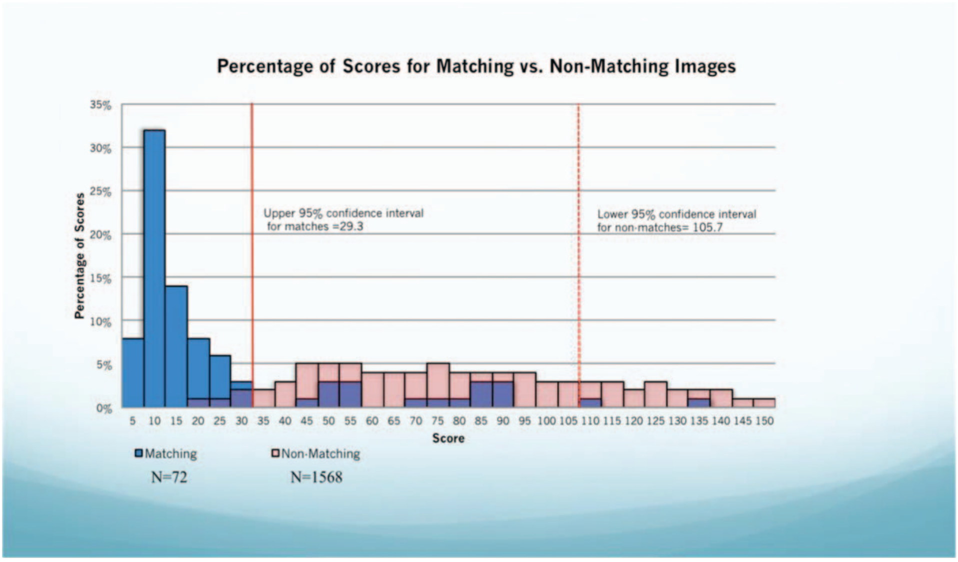

Fig. 4. The distribution of scores for "matching image pairs" and "non-matching image pairs" including their upper 95% and lower 95% confidence intervals.

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