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14. ABSTRACT

This proposal focused on the acquisition of digital images and video of cryptic marine animals in a variety of natural habitats, and under a wide range of lighting conditions. The research addressed a central question: what are the optical principles upon which crypsis is achieved by opaque organisms in shallow, nearshore marine habitats? Particular emphasis was placed on the designs of lines and edges in different types of cryptic patterning in cephalopods and fishes. Data were acquired by diving in shallow nearshore habitats such as coral reefs, kelp beds, rock reefs, seagrass meadows and sand plains. An eventual anticipated outcome is that certain bio-inspired designs of patterns in these images can find utility in refining concealment for naval materiel and personnel.

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FINAL REPORT 29 September 2023
ONR Grant # N000142012101
Crypsis in nearshore marine habitats: acquisition of light data and images with emphasis on pattern and edge designs

Principle Investigator: Roger T. Hanlon, Marine Biological Laboratory, Woods Hole, Massachusetts 02543 rhanlon@mbl.edu

Major Goals

This research focuses on a central question: what are the optical principles upon which crypsis is achieved by opaque organisms in shallow, nearshore marine habitats?

The corollary to this question is: what pattern designs are most effective on different backgrounds? This requires the development of methods to quantify camouflage.

To address these two broad questions, we need a larger inventory of images in diverse habitats under a wide range of natural lighting conditions. Thus, there were three objectives for this project:

1. Acquire field imagery data on marine animal crypsis on a wide variety of backgrounds.

2. Document and analyze disruptive pattern composition in diverse marine animal taxa.

3. Quantify light fields to assess how cryptic patterns are affected by different ambient colors.

As noted in the original proposal, the main thrust of this grant was Goal 1; Goals 2 and 3 were proposed as secondary priorities depending on diving and other logistic considerations.

Unexpected events required adjustment of research: (i) the Covid 19 pandemic in particular stopped travel for 2 years, thus field work was dramatically curtailed, although some diving was achieved in the remaining grant; (ii) to make efficient use of the funds, we concurrently focused on developing methods to quantify images that we acquired on this grant.

Accomplished under Goals

Substantial progress was achieved with this grant. In addition to acquiring many new underwater images taken under a variety of natural lighting conditions, we spent the last year analyzing ways to quantify camouflage. This report outlines **6 projects** that emanated from this small grant; each is expected to result in a journal publication.

1) "*Cephalopod adaptive camouflage efficacy evaluated with worldwide natural habitat imagery, precision human eye tracking and deep neural network analyses*" is a working title for a journal paper we are assembling from data accumulated on this grant. Much of this is based on U. Chicago Phd student Amar Rosebud's expertise in deep learning algorithms; it is combined with imagery partly assembled on this grant. This is an ongoing priority project as of this writing (October 2023). The methods (one subjective, another objective) and results provide insight into human gaze prediction during the complex visual task of concealed object detection, but also suggest which elements of cuttlefish camouflage patterns are more salient in deceiving predator visual perception.

2). "*Background matching, masquerade and disruptive camouflage by foraging* Octopus vulgaris *on Caribbean coral reefs*" is a working title for a journal paper we are assembling from data accumulated on this grant. Here we are studying Pattern as well as Color. We continue to refine our "Granularity Program" that is a fast Fourier transform of an image that is essentially a relatively simple proxy for the pattern. We compare ROIs of the animal vs surrounding substrates and objects for determining pattern type and camouflage tactic. Concurrently, collaborator Dr. Charlie Chubb is programming the MatLab to include color in the RGB space of these images, all taken under natural light conditions.

3). "*Changeable edge designs used by cuttlefish for masquerade and background matching camouflage*" is a working title for a journal paper we are assembling from data accumulated on this grant. This is a followup to the national meeting poster presented by Tufts undergrad Daisy Bonifant in 2021 entitled "Quantifying edge design in *Sepia officinalis* camouflage patterns." Given the constraints encountered in field work, we performed lab experiments with cuttlefish and developed a more precise method to compare the edge design to both the mid mantle aspect of the cuttlefish body as well as the adjacent parts of the substrate. This will provide insight into edge design.

4) "*Adaptive behaviors for defense and predation in the sand-dwelling Atlantic mimic octopus* Macrotritopus defilippi" is a working title for a journal paper we are assembling from data accumulated on this grant. This emanates from field work by R. Hanlon in February in S. Florida. The dynamic camouflage in this "open sand flat" octopus was superb and we obtained a fine sequence of patterns, one of which is unique to this species. It is an unusual form of masquerade and is one of the few ways for any animal to camouflage in open sand areas. Former Hanlon PhD student Dr. Chelsea Bennice is lead author on this study.

5) "*How exceptional arm flexibility enables complex behaviors and camouflage by octopus in diverse natural environments*" is a working title for a journal paper we are assembling from data partly accumulated on this grant. The discovered concept is this: octopuses do not show "typical" disruptive camouflage with their skin pattern per se; they do so by disrupting the recognition of the animal by positioning their malleable 8 arms in manners that do not look like an animal at all - by visually separating the arms from the rest of the octopus.

6) The Day Octopus of the Great Barrier Reef, Australia, is justly referred to as a "king of camouflage" and R. Hanlon obtained several hundred photos and 7 videos of *Octopus cyanea* on highly developed and healthy coral reefs at Lizard Island in August 2022. These will be combined with other imagery he has from other Indo-Pacific coral regions to measure camouflage diversity and effectiveness.

Training

U. Chicago PhD candidate Amar Risbud completed his dissertation entitled "Cuttlefish camouflage quantification via novel neural network approaches and hyperspectral imaging." This important work has direct impact on the present grant since the final section concerns solutions to rectifying the shift in filter tray of the HSI instrument R. Hanlon was on his PhD Committee, which was chaired by Dr. Stephanie Palmer, who has been a key player in our recent ONR grant on camouflage. He is currently a postdoc and is working with us on Publication #1 listed above.

U. Chicago undergrad Aster Taylor performed a summer internship in the Hanlon lab and continued to work on this grant for the next academic year. He helped test color and pattern analyses for underwater images of cephalopod camouflage (noted above in Accomplishments). He has been guided by Dr. Derya Akkaynak as well as R. Hanlon.

Tufts University undergrad Daisy Bonifant performed an internship in the Hanlon lab and presented a poster at the January 2022 annual meeting of the Society for Integrative and Comparative Biology. The title was "Quantifying edge design in *Sepia officinalis* camouflage patterns" and the images used for this were from this grant. ONR was acknowledged.

Dissemination

We have been active in disseminating previous and current progress in understanding basic and applied science with regard to camouflage. PI R. Hanlon gave major seminars and discussion groups in 6 venues in the past 2 years: University of Pennsylvania, Bristol Univ (UK), University of Miami, Gloucester Marine Genomics Institute (Massachusetts), Art Class for U Chicago students at MBL, Neuroimaging Conference at MBL.

The U. Miami encounter was a full 2 weeks at the university, where Hanlon was invited as the Distinguished Visiting Professor. He gave 2 university-wide talks on cephalopods and camouflage, and he led 4 formal talks with the 30 biology graduate students during this Visiting Professorship.

A major podcast (2 hrs long) was recorded and still available on Rob Reid's popular science site called "After On." This was Episode 57 and there are 40,000 avid subscribers who use this as a "go to" authentic science site. The URL is https://after-on.com/episodes-31-60/057. Camouflage and bio-inspired materials science and engineering were central themes.

In December 2021, R. Hanlon's field research on camouflage was featured in an article for the series "In the Field" for the esteemed Journal of Experimental Biology (Volume 224, Issue 24, 2021).

Importantly, 6 publications (listed in Achievements above) are expected from this grant. In all endeavors ONR interest and funding are acknowledged.

Honors

Dr. R. Hanlon was honored as Distinguished Visiting Professor at the University of Miami for 2 weeks in March 2022. This was an intensive activity in which he delivered 2 campus-wide talks as well as 4 formal discussion sessions with the 30 biology graduate students in Biology. There were extensive interactions with Biology faculty as well as colleagues at the Rosenstiel School of Marine and Atmospheric Sciences on Key Biscayne. Camouflage was a theme in all of these activities.

PI Dr. Roger Hanlon was awarded a Lifetime Achievement Award in April 2022 from the Cephalopod International Advisory Council for his multiple contributions to the science communities. This society noted his 250 peer-reviewed scientific publications as well as the 17,661 citations of his work.