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Use of high-resolution acoustic cameras to study reef shark behavioral ecology

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ABSTRACT

Shark species play an important role in shaping marine communities, ecosystems, and community assemblages, yet their high mobility and low abundances in certain locations makes studying the way they interact with these systems difficult. Here high-resolution acoustic cameras are demonstrated as effective tools to study the ecology and behavior of reef and coastal sharks that operate in the vicinity of a near-pristine coral reef atoll. The acoustic camera generated detailed imagery and size measurements from >1000 sightings of sharks that traversed a discrete corridor linking two of the atoll's distinct marine habitats, the forereef and offshore pelagic habitat with the atoll's lagoon. Daily shark density and estimated biomass values varied considerably through time, but generally approximated values calculated using less comprehensive and more labor-intensive techniques at this same atoll. Diel patterns in shark movements revealed elevated shark presence during low-light periods of the day (e.g. peak sighting density just after dusk), but weaker links between shark movement patterns and tides. Data gathered through use of this tool extends and reinforces some of the observations made of smaller numbers of sharks using traditional data collection methods while providing unique additional insights into the ways that larger numbers of sharks operate at fine spatial scales over longer periods of time. Behavioral information of this type is critical to developing effective management plans for these vulnerable species.

1. Introduction

Sharks play important roles in maintaining the health, diversity, and resilience of many marine ecosystems. Their presence in marine communities can have multiple direct or indirect effects on trophic interactions, community biomass regulation, and potential whole-ecosystem phase shifts (Bascompte et al., 2005; Ferretti et al., 2010; Heupel et al., 2014). Properly managing shark species and consequently marine ecosystems requires a deeper understanding of how sharks operate within the habitats they frequent and how they transit between habitats (Block et al., 2011; Heupel and Simpfendorfer, 2015; Speed et al., 2010). This enterprise is made doubly important given the fact that many shark species are classified as Near-threatened, Vulnerable, or Endangered (Dulvy et al., 2014).

The reduced abundance of certain shark species in a variety of locations coupled with their sometimes transient presence in ecosystems and any potential biases (Ward-Paige et al., 2010) for or against interacting with humans necessitates the exploration and adaptation of new sensing technologies to passively observe shark ecology and behavior in situ, and across a range of spatial scales. The current suite of tools used to study the spatial biology of elasmobranchs (e.g. visual surveys, acoustic telemetry, satellite telemetry, animal-borne cameras, stable isotope analysis) has expanded and continues to produce new insights into the movement patterns of sharks but many of these methods are time, labor, or cost intensive and may sometimes be less well suited to describe fine-scale patterns of utilization of particular marine habitats (Block et al., 2011; Heithaus et al., 2001; McCauley et al., 2014, 2012b). The details of these small-scale movements and behaviors are vitally important to developing a complete understanding of shark ecology and behavior. For instance, previous studies utilizing stable isotope analyses have indicated high connectivity and frequent movement of reef-associated sharks across different habitat types – reefs, lagoons and pelagic habitat (McCauley et al., 2012b) – but direct observation and quantification of these within-system movements are still scarce.

High-resolution acoustic cameras may play an important role in filling this gap in shark research. Acoustic cameras use sonar technology, or pulsed sound wavelengths to produce fast-frame, detailed imaging even in low-light, turbid environments that surpass the range capture and clarity capabilities of traditional optical cameras (Belcher et al., 2002); these cameras also allow for size measurements of detected

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targets. This technology was recently adapted for ecological applications. Acoustic cameras have been widely used for the study of salmonid behavior but they have been also employed to passively record the behavior and movements of other marine and freshwater organisms (Becker et al., 2011; Burwen et al., 2010; Holmes et al., 2006; Makabe et al., 2012). Some of the previous applications have included surveying the size structure of fish populations (e.g. cape silverside) in estuaries (Becker et al., 2011), describing the behavior of sturgeon in river spawning areas (Crossman et al., 2011), and counting salmon as they migrated upriver (Holmes et al., 2006). Acoustic cameras have also been used in trials to test the willingness of sharks to cross over experimental magnetic barriers to obtain offered baits as means of examining the efficacy of this type of experimental shark deterrent (O'Connell et al., 2014).

Data are presented here that were collected using one class of acoustic camera to study the behavior and space use of a large population of reef sharks that inhabit the waters surrounding Palmyra Atoll – a near-pristine coral ecosystem in the central Pacific Ocean. As a U.S. National Wildlife Refuge with an especially high biomass of apex predators (Sandin et al., 2008), Palmyra confers a unique and valuable opportunity to survey the abundance and size structure of an unexploited reef shark population, and study how sharks transit across reef habitats and how these movements may be related to abiotic variability. This study reports what can be ascertained using the acoustic camera about the density and size structure of sharks in this habitat as well as how shark behavior varied with time of day and tidal period – two abiotic factors that have been shown to affect movement behavior in multiple other shark populations.

A major value of using acoustic cameras in marine ecological studies is the potential to gain long-term continuous observations of large numbers of sharks interacting with important parts their environment – insight that may not necessarily be obtained through other methods. This non-invasive tool also obviates the need to capture and tag individuals, captures a greater proportion of the population than may be assessed via fishing methods, and does not influence animal behavior.

The behavioral patterns reported here demonstrate the kinds of insight that can be gained from this tool regarding how sharks operate both within and across marine habitats. Proper management of these often highly sensitive species requires access to high quality information about when sharks use a given habitat, what their ecological needs are from that space, and how these dependencies vary temporally and spatially.

2. Materials and methods

2.1. Study site

Palmyra Atoll (5°53′N, 162°05′W) is located in the central Pacific approximately 1700 km south of Hawaii. Palmyra is protected as a U.S. National Wildlife Refuge and its lagoon and surrounding coastal waters are managed as “no-take” zones. The historic isolation and modern protection of Palmyra have allowed large reef fishes, particularly sharks, to persist at high abundances that are rarely observed in inhabited and fished reef settings (Sandin et al., 2008; McCauley et al., 2012b). At least 7 species of sharks are common at Palmyra, including blacktip reef sharks (*Carcharhinus melanopterus*), whitetip reef sharks (*Triaenodon obesus*), grey reef sharks (*Carcharhinus amblyrhynchos*), Galapagos sharks (*Carcharhinus galapagensis*), tiger sharks (*Galeocerdo cuvier*), scalloped hammerhead sharks (*Sphyrna lewini*), and lemon sharks (*Negaprion brevirostris*). Other species are likely to be present, but rare.

Palmyra's islets and lagoon morphology underwent significant structural modification during World War II, including extensive expansion of a large natural channel in the Western Lagoon basin (Collen et al., 2009). This channel in its contemporary form measures approximately 1.5 km long, 80 m wide, and 8 m deep. It is characterized by a sandy bottom substratum of relatively uniform depth that is flanked by near-vertical walls of coral rubble. Turbulent flushing through the channel often creates visibility conditions which make video or diver observation difficult or impossible. The channel physically connects Palmyra's forereef and offshore marine habitats to the atoll's lagoon habitats and has been observed to be an important passageway for marine megafauna transiting between these two environments (McCauley et al., 2014).

2.2. High-resolution acoustic imaging of shark behavior

The spatially confined nature of Palmyra's main channel presents a tractable arena in which to observe the movement and behavior of sharks transiting between Palmyra's offshore/forereef habitats and lagoon environment. Dual-frequency identification sonar (DIDSON, Sound Metrics Corp., WA, USA) was used to “acoustically gate” a portion of the channel and observe sharks in this corridor (Fig. 1). DIDSON is a marine sonar device that permits high-resolution digital imaging of objects within the sonar's field of view (Belcher et al., 2002). The unit was installed mid-way along the channel at 3 m depth on the southern channel side wall. The acoustic camera near-continuously monitored a 41.7 m^3 section of channel space (McCauley et al., 2014). The field of view of the acoustic camera is pyramidal in shape with a basal width of 5 m and height of 2.5 m. The water volume of the sonar field was calculated as $V = 0.041\ D^3–0.0052\ m^3$; where D is the range selected (Han and Uye, 2009). The maximum linear distance visualized by the acoustic camera was 10 m, or approximately 13% of the width of the channel. As such, the device does not provide a comprehensive view of shark activity in the channel, but rather an unbiased sub-sample of these behavioral patterns. The acoustic camera was positioned to image a section of space directly perpendicular to the channel and was mounted on a vertical channel wall such that few, if any, sharks would transit above or behind the area viewed. The unit was operated during two daily recording sessions (each averaging 9.5 h) from 2 July

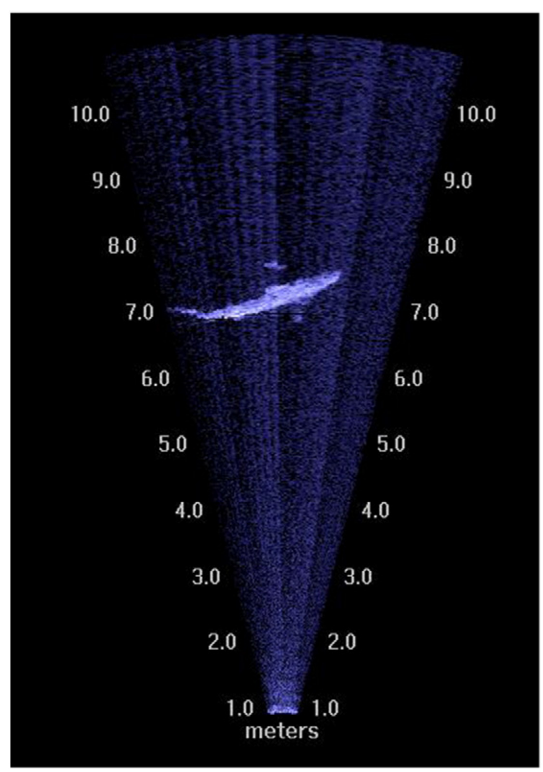

Fig. 1. Acoustic camera recorded image of a shark (2.8 m TL) moving through the sonar unit's field of view. Numbers alongside the field-of-view represent object distance from camera.