Note

Effects of anthropogenic disturbance on the abundance and size of epibenthic jellyfish *Cassiopea* spp.

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ABSTRACT

Jellyfish blooms in pelagic systems appear to be increasing on a global scale because of anthropogenic impacts, but much less is known about the link between human activities and epibenthic jellyfish abundance. The aim of this study was to investigate whether the epibenthic jellyfish, *Cassiopea* spp., were found in greater abundance, and attained larger sizes, in coastal habitats adjacent to high human population densities compared to sites adjacent to uninhabited areas on Abaco Island, Bahamas. *Cassiopea* spp. were found to be significantly more dense and larger in areas with high human population densities. Ambient nutrient levels and nutrient content of seagrass were elevated in high human population density sites, and may be one mechanism driving higher abundance and size of *Cassiopea* spp. *Cassiopea* spp. may have important effects on community structure and ecosystem function in critical coastal ecosystems (e.g., seagrass beds), and their impacts warrant further study.

1. Introduction

Jellyfish blooms appear to be increasing on a global scale, fundamentally affecting ecosystem functioning and services provided by these systems (Arai, 2001; Graham, 2001; Mills, 2001; Purcell and Arai, 2001). For example, the annual catch of one of the largest jellyfish in the world, *Nemopilema nomurai*, increased 250% from 2000 to 2003 in the East China and Yellow Seas (Dong et al., 2010) devastating fisheries in those areas. Similarly, the bloom of jellyfish within the Bering Sea region has been so severe that the Alaskan Peninsula has been dubbed the "Slime Bank" because of the large numbers of jellyfish in fishery hauls. Further, it is now estimated that jellyfish consume an average of 5% of the annual crop of zooplankton in the Bering Sea, leading to a distinct shift in food web structure (Brodeur et al., 2002).

While it is sometimes difficult to ascertain mechanisms driving pelagic jellyfish blooms, it has been suggested that several anthropogenic disturbances are likely involved. These include overfishing (Purcell and Arai, 2001; Lynam et al., 2006), nutrient loading (Arai, 2001; Lo and Chen, 2008), marine construction (Lo et al., 2008; Hoover and Purcell, 2009), introduction of exotic species (Mills, 2001), increased sedimentation (Arai, 2001) and global climate change (Brodeur et al., 2008). Many of these disturbances may

interact synergistically to drive jellyfish population blooms (Purcell et al., 2007; Jackson, 2008).

Little is known, however, about links between anthropogenic disturbances and epibenthic jellyfish populations. *Cassiopea* spp. are an epibenthic jellyfish, endemic to sub-tropical and tropical nearshore ecosystems and are sessile as medusae. *Cassiopea* spp. are nicknamed 'upside-down jellyfish' because they lie flat on their bells on soft-bottom substrates using photosynthetic zooxanthellae that live in *Cassiopea* tissues to provide the host with a substantial source of energy (Fitt and Costley, 1998; Jantzen et al., 2010). *Cassiopea* spp. have been linked anecdotally to synergistic human impacts such as eutrophication and marine construction (Arai, 2001), and may invade new habitats through ship and live rock transportation (Holland et al., 2004; Bolton and Graham, 2006). However, while there is some information regarding the distribution and abundance of *Cassiopea* spp. in coastal ecosystems (Collado-Vides et al., 1988; Holland et al., 2004; Niggl and Wild, 2009), there is very little quantitative information regarding specific anthropogenic disturbances that may influence the size of *Cassiopea* spp. populations.

Here we examine the abundance and size of epibenthic *Cassiopea* jellyfish across a gradient of human population densities. We hypothesized that *Cassiopea* spp. densities, as well as the size of individuals, would be greater in coastal areas adjacent to human population centers. As such, we attempted to link human population densities to the distribution and characteristics of an epibenthic jellyfish, an organism that may play an important role in shallow coastal ecosystems of the tropics and sub-tropics.

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2. Materials and methods

2.1 Study site

The study was conducted in nearshore habitats on Abaco Island, Bahamas (26°25'N, 77°10'W) from June to July 2009. Sites were chosen *a priori* and assigned to one of two categories: (1) adjacent to relatively high-density human population centers or (2) adjacent to uninhabited watersheds. Sites adjacent to human population centers were considered to be disturbed by human activities. Likely anthropogenic disturbances include nutrient loading through point (e.g., sewage outfalls) and non-point sources (e.g., waste water run-off), construction of artificial structures (e.g., docks), and sedimentation driven by land-use practices. As a proxy for human population size, we estimated the number of buildings within a 3 km radius of the mid-point of each site (counted in Google Earth© v 5.1) (Google Inc., 2010). Second, large tracts of many Bahamian islands, including those on Abaco, remain undeveloped and uninhabited, allowing sites with relatively little human impact to be included for comparative purposes (Layman et al., 2007; Allgeier et al., 2010).

Ten systems were chosen: five high human population density sites (84–1712 buildings; Cherokee, Hopetown, Little Harbour, Marsh Harbour, Treasure Cay) and five low human population density sites (0–10 buildings; Barracuda Creek, Cross Harbour, North Bight of Old Robinson, Snake Cay, Sucking Fish Creek) (Fig. 1). For each site, 100 points within 100 m of shore were randomly generated using ArcMap GIS v 9.3.1 (ESRI 2008) and The Nature Conservancy (TNC) habitat layers. From these points, six 'sub-sites' were selected within each of the 10 main sites. Sub-sites were visited

sequentially in the randomly-generated order and the first six sites that met two criteria were selected: (1) a low tide water depth of 2 m or shallower, as *Cassiopea* spp. are typically found in shallow water (Arai, 2001), and (2) substrate comprised of silty-sandy sediment (~0.05 mm particle size as determined by the USDA soil classification triangle; Schoeneberger et al., 1998), i.e., a proxy for flow velocity, as *Cassiopea* spp. typically occur in low energy areas (Arai, 2001). As such, all sites were in shallow water in areas without significant current flow.

Study sites were within tidal creeks, embayments, and along low energy coastlines. Tidal creek channels are formed by scouring of the calcium carbonate substrate and are typically lined with red mangrove, *Rhizophora mangle*. Moving landward, the creeks open to broad, shallow flats that often support extensive beds of *Thalassia testudinum* seagrass (Hammerschlag-Peyer and Layman, 2010; Layman et al., 2007; Valentine-Rose et al., 2007). Substrate in tidal creeks varies from hard bottom to biogenic sand; in this study, sites ranging in silt to coarse biogenic sand substrate were selected. Semi-enclosed embayments in this system are typically shallow (<3 m), and are comprised of seagrass (predominately *T. testudinum*) and sandy substrate (Yeager et al., in press). Sites selected within semi-enclosed embayments and low-energy coastlines were typically in close proximity to shorelines because of the depth criterion, and thus were often adjacent to *R. mangle* or sandy beaches.

2.2 Sampling and analytical methods

Surveys and sampling were conducted during diurnal low tides. *Cassiopea* spp. were enumerated in 10 m × 10 m plots at each of the six pre-determined sub-sites. From these plots, the first 30 *Cassiopea* spp. were measured (bell diameter). Five, 1 m × 1 m quadrats were haphazardly placed in each plot, and percent cover of submerged aquatic vegetation (SAV) was estimated. Water samples were taken to determine ambient nutrient concentrations. Water samples were immediately filtered with Whatman 0.45 μM and 0.20 μM nylon membrane filters and frozen for later analysis. Seagrass (*T. testudinum*) was also collected, if present, in each plot for nutrient analysis. Seagrass nutrient content provides insight into nutrient dynamics over a longer time frame than ambient water nutrient concentrations (Duarte, 1990; Allgeier et al., 2010). Near-surface water temperatures and salinity were measured with a portable multi-parameter water quality meter (YSI 85-10), and water depth was recorded. If boats were present, they were enumerated to provide an additional proxy for human impact at each site.

Analysis of nutrient concentrations of water and seagrass were conducted at Florida International University. *T. testudinum* blades were scraped to remove epiphytes and dried at 80 °C (n = 15 per site, if present). Dried *T. testudinum* was ground into a fine powder and % nitrogen (N) was evaluated by analyzing duplicate samples of the seagrass using a Carlo Erba CN analyzer. Percent phosphorus (P) of *T. testudinum* blades were analyzed using dry-oxidation acid hydrolysis extraction in addition to the use of a colorimetric analysis, using a CHN analyzer (Fisons NA1500) (Fourqurean et al., 1992). Total phosphorus (TP) of sample water was analyzed using the same methodologies as for %P of *Thalassia* blades. The analytical detection limit for the CHN analyzer for %P of seagrass and TP of water was 0.02 μM. Water samples were processed for ammonium (NH_4^+) and soluble reactive phosphorus (SRP) following the Indophenol blue method, using a CHN analyzer (Fisons NA1500) with a machine analytical detection limit of 0.05 μM.

To compare the number of buildings, our proxy for human population densities between high and low human population density sites, we used a Kruskall–Wallis test, as data did not meet assumptions of normality ($P < 0.05$, SAS v 9.2). Number of boats, salinity,
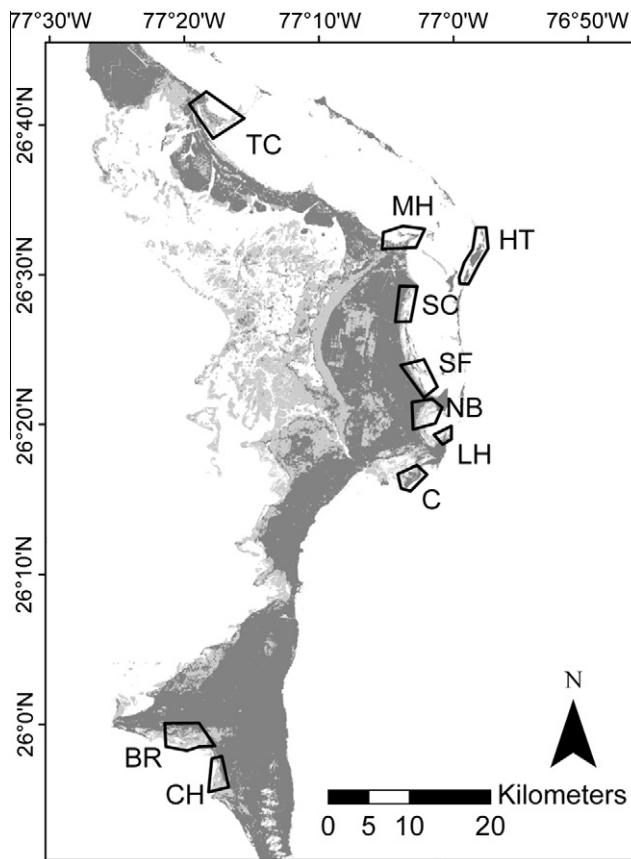

Fig. 1. Study sites on Abaco, Bahamas designated by polygons. Five sites were in high population density areas (C, HT, LH, MH and TC) and five sites were in locations with low human population densities (BR, CH, NB, SC, and SF). See Table 1 for key site codes.